FAO
FERTILIZER
AND PLANT
NUTRITION
BULLETIN

15

ISSN 0259-2495

Scaling soil nutrient balances

Enabling mesolevel applications for African realities

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 2004

ISBN 92-5-105237-9

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Foreword

In sub-Saharan Africa much attention has been focused on the quantification and estimation of nutrients entering and leaving agricultural systems, the balance showing whether the agricultural system is a net gainer or loser of soil fertility.

The FAO Land and Water Development Division is concerned with the development of technology, strategy and policy, and with the provision of advisory and technical services to FAO Members. Its programmes include activities related to the enhancement of soil fertility and land productivity for food production; land degradation assessment in drylands (LADA) and compilation of scaling subnational land-use databases are core elements.

Soil nutrient balance models quantify the flows of nutrient inputs and outputs for systems ranging from a microlevel experiment to the global level. To date, most studies of such systems have focused on either the microlevel or the macrolevel. They have provided useful data and findings for decision-makers operating at the national and international level and for researchers and individual farmers in limited realities. Their contribution to the body of knowledge should not be underestimated. However, they have tended to ignore an intermediate level that is important to broader groups of farmers, stakeholders, policy-makers and planners operating at the level of a province, district, agro-ecological zone or agro-economic system (e.g. a cotton-based farming system). This intermediate level is termed the mesolevel.

In African countries such as Ghana, Kenya and Mali, the mesolevel is the level where facilitation of production can take place and where a developing private sector can invest in a commodity or production system. It also provides a useful entry point for policy-makers at subnational level.

Acknowledgements

This work is the result of cooperation among numerous experts in different disciplines. The report was prepared by J.P. Lesschen, J.J. Stoorvogel and E.M.A. Smaling. The publication has benefited from the comments and inputs from J. Johnston (Rothamsted, United Kingdom), J. Poulisse, T. Van Den Bergen, A.P. Koohafkan and R. Roy of FAO, and from the collaborators and co-authors of the national partners: R.D. Asiamah and O. Dwomo of the Ghana Soil Research Institute, M.R. Appiah and K. Ofori-Frimpong of the Cocoa Research Institute of Ghana, P. Gicheru of the Kenya Agriculture Research Institute, and S. Kanté of the Mali Institut d'Economie Rurale.

A special thanks goes to J. Plummer for editing this publication and to Lynette Chalk for its preparation.

Preface

A 1990 macrolevel study that revealed declining soil fertility in Africa triggered microlevel case studies on nutrient flows. This report hypothesizes that a mesolevel approach can offer a valid entry point for policy-makers and private-sector intervention. The aim is to enable mesolevel stakeholders to better articulate and target scale-specific soil fertility enhancing measures.

The report synthesizes studies on soil nutrient stocks, flows and balances in order to calculate mesolevel balances for Ghana, Mali and Kenya. It explains nutrient flow calculations, shows how to construct mesolevel nutrient balances, discusses the differences between levels and between the three countries.

The mesolevel approach can consider specific management decisions and physiographic differences, and help target interventions on the basis of microlevel variations in nutrient management. In particular, it can identify constraints, use nutrient flows for planning purposes, and extrapolate results to other areas.

This report has been written for the FAO-commissioned project "Scaling soil nutrient balances". The project started in January 2002 with a literature review and the collection of data. Three case-study countries were selected and cooperation started with national research institutes, namely: the Soil Research Institute and the Cocoa Research Institute of Ghana in Ghana, the Kenya Agriculture Research Institute in Kenya, and the Institut d'Economie Rurale in Mali. In February 2003, a two-day workshop in Nairobi discussed the preliminary results of the project.

Acronyms

AEZ	Agro-ecological zone
BNF	Biological nitrogen fixation
CEC	Cation exchange capacity
CLUE	Conversion of land use and its effects
CMDT	Compagnie Malienne pour le Développement des Textiles
CRIG	Cocoa Research Institute of Ghana
CV	Coefficient of variance
DAP	Di-ammonium phosphate
DEM	Digital elevation model
GIS	Geographical information system
IFA	International Fertilizer Industry Association
IFDC	International Fertilizer Development Center
IIASA	International Institute for Applied Systems Analysis
INM	Integrated nutrient management
ISFM	Integrated soil fertility management
ISRIC	International Soil Reference and Information Centre
K	Potassium
KCC	Kenya Co-operative Creameries
LAPSUS	LandscApe ProcesS modelling at mUltidimensions and Scales
N	Nitrogen
NH_3	Ammonia
NIR	Near-infrared reflectance
NUTMON	Nutrient monitoring
P	Phosphorus
QUEFTS	Quantitative evaluation of the fertility of tropical soils
SSA	Sub-Saharan Africa
TSP	Triple superphosphate
USGS	United States Geological Survey
WISE	World inventory of soil emission potentials

Glossary

Agro-ecological zone (AEZ): FAO defines and delineates AEZs on the basis of the average annual length of growing period for crops, which depends on, *inter alia*, precipitation and temperature.

Agroforestry: Any type of multiple-cropping land use that entails complementary relations between tree and agricultural crops and produces some combination of food, fruit, fodder, fuel, wood, mulches or other products.

Available nutrients: The amount of plant nutrient in chemical forms within the soil that is accessible to plant roots, or compounds likely to be convertible to such forms during the growing season.

Biological nitrogen fixation (BNF): The fixation by bacterial cells of atmospheric nitrogen gas into organic compounds useful for life. Nitrogen-fixing bacteria exist in the soil and in association and symbiosis with plants and fungi.

Cation exchange capacity (CEC): A measurement of the ability of a soil to bind positively charged ions (cations), which include many important nutrients (calcium, magnesium and potassium). It depends on the amount and type of clay and on the amount and humification of organic matter in soil.

Compost: Mixed decayed and decaying organic matter which is a useful source of plant nutrients.

Denitrification: Reduction of nitrogen oxides (usually nitrate and nitrite) to molecular nitrogen or nitrogen oxides with a lower oxidation state of nitrogen by bacterial activity (denitrification) or by chemical reactions involving nitrite (chemodenitrification).

Fallow: Arable land not under a rotation of crops that is set aside for 1–5 years before being cultivated again, or land usually under permanent crops, meadows or pastures that is not being used for that purpose for at least one year. It includes arable land normally used for temporary crops but temporarily under grazing.

Farming system: Population of individual farm systems that have broadly similar resource bases, enterprise patterns, household livelihoods and constraints, and for which similar development strategies and interventions would be appropriate. Depending on the scale of the analysis, a farming system can encompass a few dozen or many millions of households.

Fertilizer: Any organic and inorganic material of natural or synthetic origin (other than liming materials) that is added to a soil to supply one or more plant nutrients essential to plant growth.

Food security: A situation that exists where all people at all times have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life.

Integrated nutrient management (INM): Judicious manipulation of nutrient stocks and flows in order to arrive at a satisfactory and sustainable level of agricultural production at minimum environmental cost.

Macrolevel: A large scale level that corresponds to the continental or national level.

Manure: The excreta of animals, with or without an admixture of bedding or litter, fresh or at various stages of further decomposition or composting.

Mesolevel: An intermediate scale level that corresponds to the farming-system, region or district level.

Microlevel: A small scale level that corresponds to the village or farm level.

Nutrient balance: The difference between the sums of nutrient inputs and outputs on agricultural land.

Nutrient flow: Flux of nutrients from one unit to another unit. This study defines the principal unit as the soil of agricultural land to the depth of root growth.

Nutrient stocks: Amount of nutrients of a certain unit, e.g. soil or dunghill.

Soil fertility: The quality of a soil that enables it to provide adequate amounts of nutrients in a proper balance for the growth of specified plants or crops.

Soil management: The sum total of all tillage and planting operations, cropping practices, fertilizer, lime, irrigation, herbicide and insecticide application, and other treatments conducted on or applied to a soil for the production of plants.

Sustainable agriculture: Agricultural and agrifood systems that are economically viable and meet society's need for safe and nutritious food, while conserving or enhancing natural resources and the environment for future generations.

Volatilization: The transformation of non-gaseous substances in a defined system and the loss of such gas from the defined system. For example, the loss of ammonia gas from a nitrogen-fertilized soil.

Chapter 1

Introduction

RATIONALE

Together with water availability and the absence of weeds, pests and diseases, soil fertility is the most important biophysical yield-determining factor. In the tropics, soils are generally older and poorer than in the Northern Hemisphere. This holds particularly for the vast erosional plains of Africa. In many places, the already low level of fertility tends to decline further as farmers generate many nutrient outputs in crops and through processes such as leaching and erosion without applying matching inputs in the form of fertilizers, manure and biological nitrogen fixation (BNF). Countries following structural adjustment programmes have abolished subsidies on fertilizers, resulting in a significant reduction in their use on staple food crops. For cash crops, fertilizer use depends principally on world market prices, which respond to supply and demand management and attitudes towards market protection.

In the past ten years, much attention in sub-Saharan Africa (SSA) has focused on the quantification and estimation of nutrients that enter and leave agricultural systems. The balance between these nutrient inputs and outputs shows whether the agricultural system is a net gainer or a net loser of soil fertility. An FAO-commissioned macroscale study (Stoorvogel and Smaling, 1990) showed nitrogen (N), phosphorus (P) and potassium (K) balances for land-use systems and country scales, and revealed that soil fertility in Africa is following a downward trend. Densely populated and hilly countries in the Rift Valley area (Kenya, Ethiopia, Rwanda and Malawi) have the most negative values, because of a high ratio of cultivated land to total arable land, relatively high crop yields and soil erosion.

The study triggered numerous case studies at plot, farm and village levels with different degrees of sophistication. Some studies focused on the measurement of some flows, others on the linkage between nutrient balance and farm household economic performance, and others on participatory learning and action towards improving soil fertility and its management. The results are available in books, special issues of journals (e.g. Buresh *et al.*, 1997; Smaling, 1998; Smaling *et al.*, 1999; Hilhorst and Muchena, 2000; Scoones, 2001; Tian *et al.*, 2001; Vanlauwe *et al.*, 2002), M.Sc. and Ph.D. theses, a 'toolbox' and a Web site (http://www.nutmon.org). The body of knowledge has grown significantly, but the linkage to soil fertility policies is modest (Scoones and Toulmin, 1999). Currently suggested 'best bets' and 'best practices' stem more from local experiences rather than from a thorough constraint analysis. Policies for soil fertility and its management evolve mainly at national and subnational levels.

There is a need to develop entry points at a level lower than 'continent' and 'country'. A country soil-fertility map shows areas with richer and poorer soils, but provides no clues for the mesolevel stakeholder and the farmer. Nor do such maps show diversity at farm level. The present study hypothesizes that between country level (macrolevel) and farm level (microlevel) there is an important mesolevel, where facilitation of production can take place, and where the private sector may invest in a commodity or a production system. Therefore, the evaluation of soil fertility and the manipulation of the nutrient flows, i.e. integrated nutrient management (INM), should take place at three relevant spatial scales, which are also stakeholder-specific scales.

This study uses three scale levels: macrolevel, mesolevel and microlevel. These scale levels are not fixed, but provide an indication of the order of magnitude. This study defines the macrolevel as the nation, but it can also refer to a continental or global farming-system level (FAO, 2001b). The macrolevel nutrient balance calculation uses data that are available for each country, such as FAOSTAT data and global geographical information system (GIS) data sets. This makes the approach applicable in principle for each country. The mesolevel coincides with the level of the province, district or agro-ecological zone (AEZ). This study defines the mesolevel as an agro-economic rather than a geographical entity, e.g. cotton-based or dairy-based farming systems. Such units often have a commercial component that allows for intensification and expansion. Farm-level studies have revealed that a cash economy component in farming systems tends to drive soil fertility management, and constitutes a suitable entry point for policy and private-sector intervention. Finally, this study defines the microlevel as the farm or village level, but it can extend to the nutrient management group or gender.

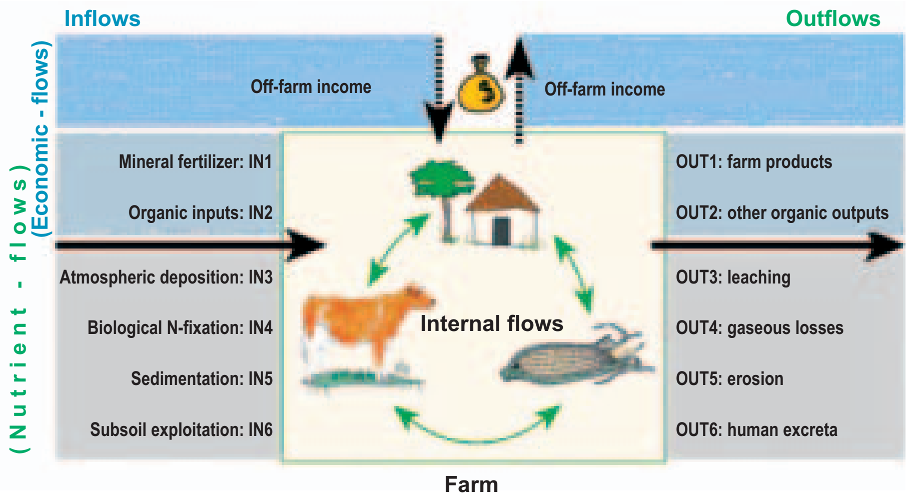
The innovation in this report is the introduction of a mesolevel, and the hypothesis is that it adds value to the current macrolevel and microlevel knowledge. However, mesolevel data originate largely from macrolevel and microlevel data because most studies and data are available at these scales. Hence, it is necessary to apply procedures to disaggregate national data in order to show spatial variability within a country. At the same time, it is also necessary to aggregate results from studies at the farm level without crude averaging and without neglecting variability in complex farming systems.

THE NUTRIENT BALANCE MODEL

A nutrient balance for a 'system' consists of the sum of nutrient inputs minus the sum of nutrient outputs. This system always represents a particular spatial scale, and it can range from a small soil aggregate to the entire globe.

Figure 1 shows the possible nutrient flows that could influence a nutrient balance. Flows IN1 and OUT1 and, to a lesser extent, IN2 and OUT2 are so-called 'easy flows' because they are relatively easy to measure or calculate, and it is possible to express their values in monetary terms. The other flows are 'difficult flows', not normally measured on a routine basis, and less easily retrievable from land and agricultural statistics. Moreover, economic assessments seldom consider

FIGURE 1
Nutrient flows and economic flows influencing the nutrient balance and household budget



Source: after De Jager *et al.* (1998).

their physical or off-site effects. This report considers flows IN6 and OUT6 only at the microlevel. At higher scale levels, IN6 is too difficult to capture, and OUT6 would lead to double counting, as all nutrients in harvested products count as OUT1. It is possible to calculate a nutrient balance for each scale level. However, as data limitations between levels are different, calculation procedures also differ. This study considered all scale levels only in terms of N, P and K. Where data sets expressed P and K in terms of P_2O_5 and K_2O, the values were divided by 2.3 and 1.2 respectively.

Determining a nutrient balance has its shortcomings. First, it shows the results of a static input–output balance, but it does not take changes in nutrient stocks into account. Second, the application is data intensive. Third, given the large diversity between farms, sampling methodology, sample density, and representativeness become issues in how to aggregate farm-level results to a subnational or national level. Nutrient flows may provide a useful tool for farmer understanding of soil management problems, but interventions still need to be profitable. At the same time, nutrient budgeting provides a template for economic budgeting and, therefore, for understanding higher-level determinants of farmers' soil management practices (Lynam *et al.*, 1998).

OBJECTIVE

The objective of this report is to revisit and synthesize existing studies on soil nutrient stocks, flows and balances at the macrolevel and the microlevel, and to calculate mesolevel nutrient balances for three SSA countries (Ghana, Kenya and

Mali). The macrolevel 'big picture' should help in targeting profitable soil fertility technologies at the mesolevel, taking functional microlevel diversity into account. As such, the project's ultimate objective is to provide a methodology for mesolevel stakeholders to better articulate and target scale-specific soil fertility enhancing measures and so ensure that food security policies are sustainable in the longer term. This methodology can then also fit within FAO's normative programmes.

STRUCTURE

The report consists of five chapters and a number of annexes. Chapter 2 describes the selection of the three pilot countries, the study areas and the different farming systems to test the mesolevel method. Chapter 3 explains the methodology for calculating the nutrient flows for the different scale levels. Chapters 4 and 5 present and discuss the results of the nutrient-balance calculations for the different scale levels. Soil fertility specialists and mesolevel stakeholders discussed the results at a workshop with 27 participants in Nairobi (17–18 February 2003). Chapter 5 incorporates the outcomes of the workshop, while Annex 11 contains the abstracts of presentations by participants at the workshop.

Chapter 2

Study area descriptions

COUNTRY AND STUDY AREA SELECTION

Given the pilot character of the study, the following criteria determined the selection of three African countries:

- The relative availability of data on soil fertility and nutrient balances at macrolevel and microlevel should be different.
- The countries should cover major AEZs and landscapes in SSA.
- Parts of the countries should have farming systems with a cash crop or other market-oriented agricultural component.

These criteria led to the selection of Ghana, Kenya and Mali. It is possible to characterize the three countries as follows:

Ghana:

- Few data available.
- Representative of the tree-crop farming system (FAO, 2001b).
- Cocoa production is 11.9 percent of world production.
- Cocoa-based farming system in Nkawie and Wassa Amenfi districts.
- Local research groups: the Soil Research Institute and the Cocoa Research Institute of Ghana (CRIG).

Kenya:

- Many data available.
- Representative of the highland temperate mixed and maize-mixed farming systems (FAO, 2001b).
- Tea production is 8.6 percent and coffee production is 1.0 percent of world production.
- Tea–coffee–dairy farming system in Embu District.
- Local research group: Kenya Agriculture Research Institute.

Mali:

- Moderate quantity of data available.
- Representative of the agropastoral millet-sorghum farming system (FAO, 2001b).
- Cotton production is 1.0 percent of world production.
- Cotton-based farming systems in the Koutiala Region of the Compagnie Malienne pour le Développement des Textiles (CMDT).
- Local research group: Institut d'Economie Rurale.

The three study areas fall within different AEZs. The two districts in Ghana are part of the West African Equatorial Forest Zone with high, bimodal rainfall. This zone has a growing period of more than 270 d and depleted soils with a low

TABLE 1
Soil properties of the topsoil (0–20 cm) of uplands for the different AEZs

Zone	pH (H_2O)	C (g/kg)	N (g/kg)	CEC (cmol/kg)	Base saturation (%)	Available P (mg/kg)	Total P (mg/kg)
Equatorial Forest	5.6	22.5	1.6	9.2	29	12.1 (Bray I)	413
Northern Guinea Savannah	5.8	12.1	1	7.1	69	2.9 (Bray I)	367
Tropical Highland	4.5	-	6.1	22.5	-	2.9 (Olsen)	2 068

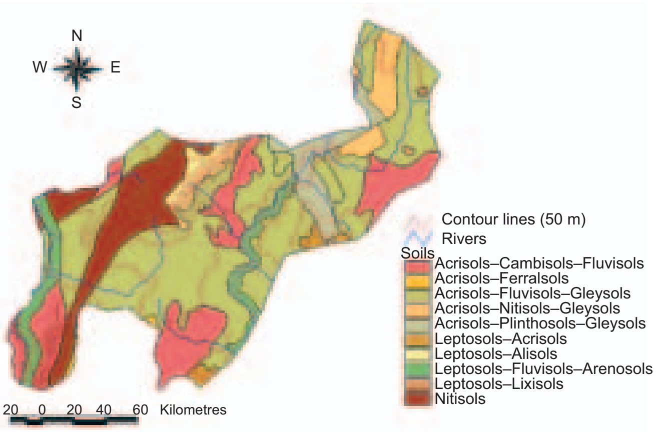
Sources: Data for Equatorial Forest Zone and Northern Guinea Savannah Zone adapted from Windmeijer and Andriesse (1993); data for Tropical Highland Zone from Smaling *et al.* (2002) (average of AEZ1–AEZ3).

base saturation (Table 1). Embu District in Kenya falls within the East African Tropical Highland Zone. Owing to the volcanic origin of the area, the soils are relatively fertile. The available P is low owing to P fixation. Rainfall increases with altitude and has a bimodal distribution. This results in a growing period of more than 270 d. The Koutiala Region in Mali belongs to the Northern Guinea Savannah Zone of West Africa, characterized by a monomodal rainfall distribution (900–1 500 mm/year). This results in a growing period ranging from 165 d in the north to 270 d at the southern boundary (Windmeijer and Andriesse, 1993). The soils are sandy and very poor in nutrients (Table 1).

GHANA

Ghana produces crops such as millet and sorghum in the drier north of the country, and cassava and cocoa in the wetter south. Cocoa is the most important crop in the country in terms of cultivated area, exports and employment.

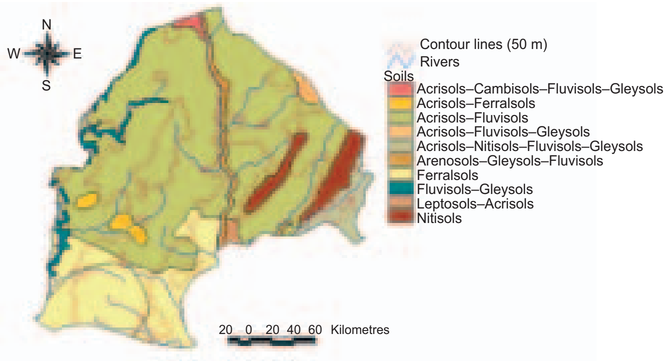
FIGURE 2
Soil map of Nkawie District



Source: Soil Research Institute (1999).

The areas selected for the mesolevel analysis were Nkawie District in Ashanti Region and Wassa Amenfi District in Western Region. Although Nkawie District is more suitable for cocoa, there has been a large expansion in the cocoa area Wassa Amenfi District in recent decades because of land scarcity in Ashanti Region. Wassa Amenfi District is located in southwest Ghana and has a higher annual rainfall than Nkawie District, which is less favourable for cocoa

FIGURE 3
Soil map of Wassa Amenfi District



Source: Soil Research Institute (1999).

production. Major soils in Wassa Amenfi District are strongly leached and poor Ferralsols, compared with more fertile Acrisols in Nkawie District (Figures 2 and 3). Cocoa yields in the two districts are similar in spite of the differences in suitability. Differences in land use history in the two districts may explain this fact. The soils in Nkawie District have experienced more intensive use and for a longer period than those in Wassa Amenfi District, which may still contain part of the nutrients liberated after forest clearing. The landscape in this part of Ghana is mainly undulating, with Acrisols and Ferralsols at the top and on the slopes, and Gleysols and Fluvisols in the valley bottoms. Cocoa is grown mainly on the slopes and the top, because the valley bottom areas are too wet during the rain season (Adu, 1992).

Cocoa-based farming system

The cocoa crop covers almost 30 percent of the arable land. The main growing areas are in central and southwest Ghana. The best conditions for cocoa are a permeable soil with a good structure, annual rainfall of 1 250–1 500 mm and a soil pH of 5.6–6.5. The average cocoa farm covers 1.2 ha but there are a few large plantations. Most farmers consider cocoa a low input crop and do not apply fertilizer. Mineral fertilizer and manure inputs go to annual crops such as maize, plantains and yams. Failure of these crops means that farmers lose the whole investment (seeds, fertilizer, pesticides, etc), while cocoa as a permanent crop provides a harvest each year.

Cocoa production without shade is small in the absence of fertilizer. Farmers normally burn small parts of the secondary forest to open up new cocoa land. After clearing, they intercrop the cocoa with maize, yams, plantains and cassavas. In the early years, plantains grow fast and provide shade. After five years, the cocoa plants have developed a closed canopy and farmers then grow the crop as a monoculture. Yields decrease after 20 years, but production is possible for up to 50 years. The farmers usually plant 300–400 cocoa trees per hectare. The Cocoa Research Institute of Ghana (CRIG) advises leaving at least 6–8 large trees per hectare for shade. These species (preferably leguminous) need to be selected during forest clearing (CRIG, 2001). Where the canopy is not closed, farmers sometimes plant other leguminous trees such as *Gliricidia*.

The farmers normally remove the lower branches of the cocoa trees to improve air circulation and facilitate harvesting. These branches are normally left on the ground, together with all the leaves that fall off. This results in a thick litter layer, which is important for nutrient cycling, but decomposition is rapid because of the high temperatures and rainfall (Ofori-Frimpong and Rowell, 1999). The litter layer also protects the soil against erosion and prevents weed growth. Soil erosion is not a widespread problem in the cocoa area because vegetation covers most of the land.

Economic importance

The cocoa industry has been the driving force of Ghana's economic development and expansion through employment of rural labour, development of trade and commerce, savings, investment, and growth of the money economy (Asante, 1997).

Between 1990 and 1999, the industry contributed an average of 31 percent of total foreign exchange earnings annually and an average of 12 percent of total annual government revenue. It is the source of income and livelihood for about 25 percent of the population (ISSER, 2000).

Small-scale farmers dominate the cocoa industry in Ghana. The indications are that the industry will continue to play a significant role in the national economy. Efforts to place the industry on a firm footing have been ongoing. Successive governments have supported cocoa cultivation through producer price stabilization, the provision of research and extension services for the control of cocoa pests and diseases, and the dissemination of improved agronomic practices.

The average cocoa yield is about 300 kg/ha (Table 2), which is low compared with the potential yield of 1.0–1.5 tonnes/ha. Several factors caused cocoa production in Ghana to decline between 1960 and the mid-1980s. However, one important factor that has not attracted much attention is the relationship between soil fertility and cocoa production. Appiah *et al.* (1997a) observed that the removal of plant nutrients through harvesting over long periods without replenishing could be a major cause of the decline in production. A 1990 CRIG survey showed that virtually no cocoa farmers in Ghana included soil fertility maintenance in their farm management programmes (Donkor *et al.*, 1991). There may be substantial nutrient recycling from the surface litter and root decomposition, but these are not external inputs.

TABLE 2
Production and export data for cocoa in Ghana

	1970	1980	1990	2000
Harvested area (ha)	1 451 000	1 200 000	693 249	1 500 000
Production (tonnes)	406 000	277 200	293 355	436 600
Yield (kg/ha)	280	231	423	291
Export (tonnes)	367 362	194 679	248 970	360 250

Source: FAOSTAT.

In 1990, a research programme began to evaluate the agronomic, environmental, social and economic implications of fertilizer use on some peasant cocoa farms in Ghana including Nkawie District. The annual fertilizer application rates were 50 kg P/ha and 64 kg K/ha (Appiah *et al.*, 1997b). The outcome of the research work at the CRIG indicated that:

- the yield increase from fertilizer application was 62 percent in the first year, 100 percent in the second year, 116 percent in the third year and 107 percent in the fourth year;
- fertilizer application improved farmers' incomes considerably, which also provided sufficient incentive for farmers to adopt the technology;
- fertilizer application improved cocoa qualities such as bean size and weight;
- the combination of fertilizer and fungicide increased yield considerably in black-pod-prone areas.

Because of the positive results obtained from the trials, and in line with the Government's poverty reduction strategy through cocoa productivity improvement, the CRIG is providing technical advice to many district assemblies in order to alleviate poverty among cocoa farmers in the districts. This project has commenced and it is collecting relevant data for analysis.

KENYA

Kenya has a wide variation in topography and climate. This results in many different AEZs and accompanying land uses. Most tropical crops, except high-rainfall tree crops, occur in Kenya. Coffee and tea are the major cash crops and important foreign-exchange earners. These crops are cultivated mainly in west Kenya and on the slopes of Mount Kenya.

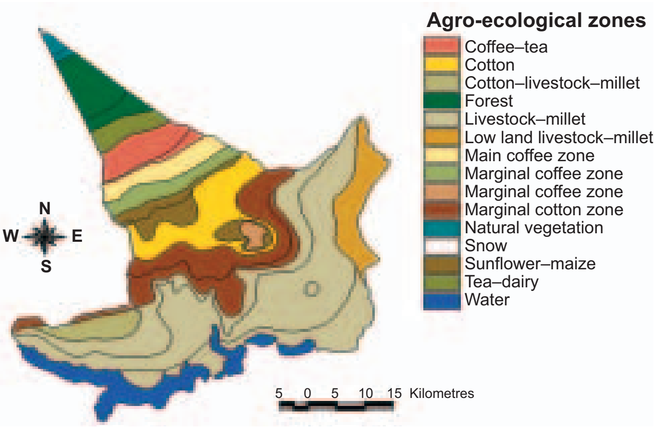
The study area for mesolevel data collection was the tea–coffee–dairy zone of Embu District on the slopes of Mount Kenya. This district shows the typical agro-ecological profile of the windward side of Mount Kenya, from the hot, dry, lower zones in the Tana river basin at 700 m to the cold, wet, upper zones above 2 000 m. The upper highlands are forested. The district consists of five different AEZs (Table 3). The tea–coffee–dairy zone of Embu District is mainly in AEZ2 (Figure 4).

TABLE 3
Characteristics of the AEZs in Embu District

Characteristic	AEZ1	AEZ2	AEZ3	AEZ4	AEZ5
Altitude (m)	1 770	1 590	1 320	980	830
Mean temperature (°C)	16.8	18.2	20.2	21.4	22.6
Rainfall (mm)	1 750	1 400	1 200	900	800
Main soil types	Andosol/Nitisol	Nitisol	Nitisol	Luvisol	Lixisol
Main land use	tea/dairy	tea/coffee/ dairy	coffee/maize	tobacco/food crops	livestock/ shifting cultivation

Source: after Jaetzold and Schmidt (1983).

FIGURE 4
AEZs of Embu District



Source: after Jaetzold and Schmidt (1983).

The data collected at subdistrict level covers the areas of Manyatta and Nembure (northern part of the Runyenjes division). The two divisions have a surface area of 219 km^2, of which 195 km^2 is cultivated (Government of Kenya, 2001).

The tea–coffee–dairy farming system

The tea–coffee–dairy farming system in Embu District is in use at altitudes of 1 590–1 830 m, where the average annual rainfall is 1 250 mm and the evapotranspiration is 1 400 mm (Jaetzold and Schmidt, 1983). Soils in this farming system are mainly well-drained Nitisols with a moderate fertility status (Table 1). The local farmers grow various crops for cash and subsistence. The area is densely populated (86 households/km^2). The number of smallholdings in the area is about 21 000, which results in an average cultivated area of 0.9 ha per smallholding (Government of Kenya, 2001).

Tea

Tea is Kenya's second most important foreign-exchange earner, contributing more than 20 percent of the country's total export earnings (Government of Kenya, 1995). The production and export of tea has been increasing since 1970 (Table 4). In Embu District, where small-scale farmers grow the majority of the crop, tea production has also been on the increase. In 1991, tea production in the district was 22 600 tonnes and it had increased to 30 100 tonnes after five years, earning the farmers a total of US$59 million (Government of Kenya, 2001). However,

TABLE 4
Production and export data for tea in Kenya

Tea	1970	1980	1990	2000
Harvested area (ha)	40 278	76 541	96 981	122 236
Production (tonnes)	41 077	89 893	197 000	236 286
Export (tonnes)	41 633	84 455	166 405	217 282

Source: FAOSTAT.

TABLE 5
Production and export data for coffee in Kenya

Coffee	1970	1980	1990	2000
Harvested area (ha)	84 983	102 400	153 100	179 000
Production (tonnes)	58 300	91 334	103 900	100 000
Export (tonnes)	53 855	80 334	114 381	86 957

Source: (FAOSTAT).

there are various constraints on tea cultivation. These include: lack of access to credit facilities, low world tea prices, poor road infrastrcture, a poor marketing system and inadequate storage facilities.

Coffee

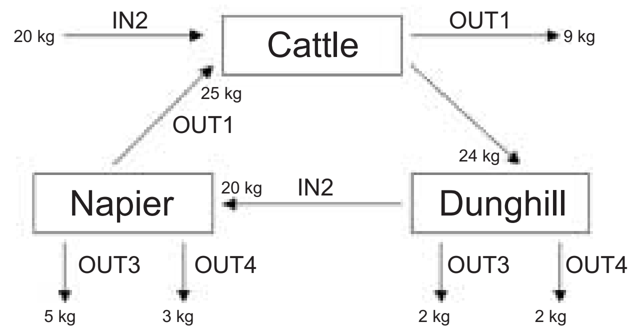
Until 1990, the coffee industry was the major foreign-exchange earner for the country, contributing about 25 percent of the country's total export earnings (Government of Kenya, 1995). Coffee production peaked in 1994/95 owing to improved international coffee prices, good weather and good incentives to farmers. Coffee production and exports then declined (Table 5). The revenue from sales of coffee from Embu district rose from US$5.5 million in 1991 to US$12.9 million within five years (Government of Kenya, 1998). Various factors caused the decline in coffee production after 1994/95. These included: suboptimal application of fertilizers and other chemicals due to high prices, the floating of the Kenyan shilling against major currencies, low world coffee prices, poor infrastructure, lack of access to credit facilities, poor international supply management, and new producers on the world market.

Dairy

The most important role of farm livestock is the collection, conservation and concentration of nutrients at farm level. However, the mode and extent of nutrient recycling depend on the type (large or small ruminants, pigs, rabbits and poultry) and number of livestock in a farming system (Lekasi *et al.*, 2002). The integration of livestock and crop cultivation in the same economic entity makes such a system a mixed or crop-livestock management system. One important advantage of integrated farming is the opportunity to convert by-products and waste from one activity into inputs for another. The livestock provides inputs such as manure for crop production, with crop products such as residues and fodder going to livestock production. Cross-breeds kept in so-called zero-grazing units dominate the small-scale dairy system practised on farms of up to 1 ha in the Embu tea–coffee–dairy zone.

The agriculture sector in Kenya began to adopt the zero-grazing system in 1979 in an effort to overcome the constraints of smallholder dairy farming, i.e. lack of grazing land, low productivity of dairy cows, low quality of fodder, prevalence of diseases, and lack of finance. The cattle remain inside all year round (which

FIGURE 5
Quantitative representation of nitrogen flows (kg/head/year) in a zero-grazing system in Kenya



Source: Van den Bosch *et al.* (1998b).

prevents diseases), and they receive fodder, mainly Napier grass, through a 'cut and carry' system (Mango, 2002). Figure 5 shows the nutrient flows between the main components of the zero-grazing system. This system has proved successful in Embu District.

Smallholder dairy production in Kenya has been a major success story in SSA. Owing to rapid population growth, increased urbanization and the potential to use relatively intensive technology, the dairy industry has offered many smallholders greater income opportunities compared with other agricultural activities. Kenya Co-operative Creameries (KCC) controls most dairy processing and marketing in Kenya. It handles 90 percent of all marketed processed milk and is the major buyer at farm level. Milk production has increased significantly since the introduction of exotic breeds (Table 6). The informal dairy market consists of direct sales of raw milk by producers or local traders to individual consumers, and of local sales of raw milk by peri-urban and rural cooperatives. Of the milk marketed by smallholders, about 60 percent reaches consumers in an unprocessed form through the informal market (Staal and Shapiro, 1998).

The National Dairy Development Project recommends breeds with a large milk yield potential of 9 kg/day per cow. The dry matter intake will be about 10 kg/day per cow, including protein-rich supplements (Mogaka, 1996; Kariuki, 1998).

MALI

In Mali, only that part of the country south of the Sahara is suitable for agriculture. The major crops are millet, sorghum, cotton and pulses, with much rice being

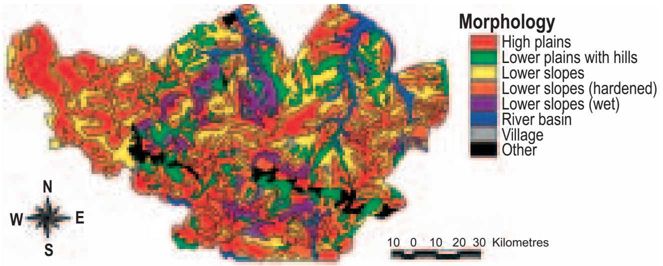
TABLE 6
Production data for milk in Kenya

Milk	1970	1980	1990	2000
Cattle	8 600 000	10 000 000	13 793 000	13 794 000
Production (tonnes)	820 037	920 000	2 320 000	2 250 000
Export milk equivalent (tonnes)	50 566	2 361	4 679	2 841

Source: FAOSTAT.

grown in the temporarily flooded and irrigated areas along the Niger River. Cotton is the main cash crop. For the mesolevel analysis, this study selected the CMDT Koutiala Region of Mali-Sud because it is the centre of the cotton zone and produces 30 percent of the country’s cotton. The region has a surface area of 18 600 km² and a population of almost 600 000 people (CMDT, 2000). The CMDT Koutiala Region is larger than the governmental Koutiala Region (Cercle de Koutiala). The CMDT region was preferred because more data are available. Most agricultural land lies on the lower slopes (Figure 6) and the soils in the region are mainly Luvisols. The average annual rainfall is 1 040 mm.

FIGURE 6
Morphological map of the Cercle de Koutiala



Source: after Sissoko (1999).

The cotton-based farming system

Production system

Large parts of the CMDT Koutiala Region have been in permanent use for more than ten years. An average farm uses 11 ha annually for the production of cotton, cereals and livestock. Livestock, including the draught animals, also function as a guarantee for loans. The cultivated area has increased in line with the population, i.e. at 3 percent per year. The total cultivated area in 1999 was 4 940 km², which is 27 percent of the total area of the CMDT Koutiala Region. The remainder of the area was under fallow, pasture and forestry.

Crop system

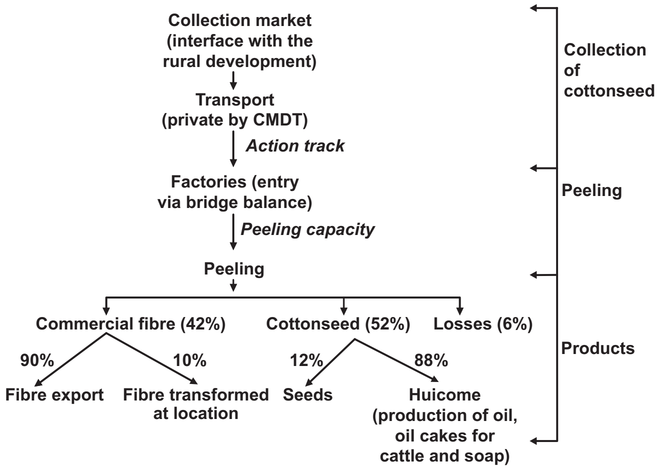
Cotton-cereal and cotton-cereal-cereal rotations dominate the crop system. Cotton is the principal cash crop, while sorghum, millet and maize are the principal food crops. The local farmers use substantial quantities of manure, compost and domestic waste, and they apply mineral fertilizers to cotton (Dembélé, 1994).

Livestock system

The area had 436 200 head of cattle in 1997/98 (CMDT, 1999). The majority of the cattle are sheperded in herds on the pasture from the beginning of the rainy season until the end of the harvest period in order to protect the cultivated fields from destruction. The sheep, goats and asses are tethered while the draught oxen are kept on the fallow fields (Bosma *et al.*, 1996). Residue grazing begins just after the harvest. During this period, animals belonging both to the farm and from outside can graze the crop residues freely. Many animals do not survive the dry season because of insufficient forage and feed.

FIGURE 7

Cotton system: industrial part, market to product



Source: CMDT, 1999.

Cotton marketing and logistics

According to Soumaré (2001), there are three principal systems of cotton production in the world:

- managed-monopoly or integrated system;
- controlled-liberal or subsidized-liberal system; and
- completely liberal system.

Managed-monopoly or integrated system

This is a vertically integrated system producing and marketing cotton fibre and, in certain cases, oil and cotton-oil cakes. The organization is structured around the main stakeholder (the cotton company), which has the responsiblity for peeling the cottonseeds and marketing the cotton fibre (Figure 7). This system has the advantage of using cotton as a socio-economic development tool (against poverty), but the cost of production and the charges are relatively high. This system exists in the countries of French-speaking Africa.

Controlled-liberal system or subsidized-liberal system

This system involves subsidizing the producer price of cottonseed in order to stimulate production. Countries that practise this system include the United States of America, the cotton-producing countries of Europe (Spain and Greece) and the majority of the other large cotton-producing countries of the world (India, China and Pakistan). This system has the advantage of easy development of the cotton industry with professional private participants, but it needs state financial support. For example, the United States of America spent US$1 700 million on subsidizing its cotton production in 1992/93 (Soumaré, 2001). Egypt, which is the leading African producer, gives more than US$165 million in subsidies to its producers (Barry, 1998).

Completely liberal system

Under the completely liberal system, market forces control the functioning of the system and stimulate competition between all stakeholders. This system places no burden on national finances but production becomes unstable in the absence of protection and stabilization, and fluctuates according to market supply and demand. Ghana and Nigeria use this system. It has been a success in Argentina and Australia, where large farms exist with the capacity to adapt to market realities.

The Malian system

With cotton production exceeding 520 000 tonnes in the peak year of 1997/98, Mali is the leading cotton producer in SSA, with its increasing exports reflecting this position (Table 7). Mali's cotton producers have achieved this result without any state support. The key to this success of the CMDT, according to its president, is the character of the integrated system (Figure 7).

Small-scale farmers are the main producers of cotton, primarily in the zone influenced by the CMDT and partly in that of the Office de la Haute Valée du Niger. These farmers receive support from the CMDT council for the entire cotton-based system (cotton, cereals and leguminous crops). They receive inputs (seeds and mineral fertilizer) from the CMDT in cooperation with the National Bank of Agricultural Development. The CMDT has the monopoly of the purchase and peeling of cottonseeds in its intervention zone. Village associations manage the logistics and constitute the unit of credit for the National Bank of Agricultural Development. The amount of credit granted depends on the level of production of the village association, which always refunds the amount through the sale of cotton. In addition to the management of credit, the village association deals with the marketing of the cottonseed stored in the village silos before its transport to the factories of the CMDT. In addition, the CMDT is responsible for public services (installation of rural roads, rice fields, water facilities, promoting literacy, etc). This system has made it possible to develop not only the cotton sector but also the cereal sector. The cotton zone is also the main cereal and livestock zone of Mali. The CMDT zone produced 1 322 000 tonnes of cereals in 1999/2000 and was able to export a cereal surplus of 534 000 tonnes (Soumaré, 2001). Because of the relatively high maize yields and intensification of this crop, the cereal balance remains largely positive (400 kg/person).

However, the Malian system has encountered difficulties, e.g. the cotton boycott by groups of producers in 2000/01. Among the problems, Soumaré (2001) noted:

- poor management of the credit and debts of the village associations;
- disintegration of the village associations and the crumbling of social cohesion;
- declining cotton yields;
- falling prices for cotton fibre on the world market;

TABLE 7
Production and export data for cotton in Mali

Cotton	1970	1980	1990	2000
Harvested area (ha)	65 703	102 352	194 423	227 805
Production (tonnes)	52 762	108 052	276 023	242 772
Export (tonnes)	32 617	78 013	98 956	173 000

Source: FAOSTAT.

- poor management and provision of inputs by the CMDT;
- lack of an audit and information system and internal control, adapted to the current situation of the CMDT;
- increase in the financial needs of the CMDT and in the capacity of the local banking system to satisfy all needs.

Chapter 3
Methods

As data limitations between scale levels are different, nutrient-balance calculation procedures also differ. This chapter explains the methodology for the nutrient-balance calculation for each scale level, and provides an overview of the different procedures and data for each scale level.

MACROLEVEL

This study calculated the macrolevel nutrient balance on a grid basis. As land use is the main driver of the nutrient flows and balance, it formed the basis for the methodology. A procedure exists to create a land-use map, based on suitabilities, and showing the most likely crop distribution. This study combined the grid map (cell size of 1 km) with other spatial data that were necessary for the nutrient-balance calculation. As exported to MS Access, the resulting attribute table contained all the spatially explicit data: livestock densities, soil, rainfall, Harmattan dust, erosion-sedimentation and irrigated areas. The program MS Access performed the calculation of the soil nutrient balance and the results were exported to ArcView. The final outcomes require aggregation where the intention is to use them for display purposes because a 1-km grid is too detailed for the macrolevel. Where possible, all input data were averaged for the years 1997–99.

Land-use map

It is not possible to link land cover data as retrieved from satellite images to management data because land cover does not describe crop distribution. On the other hand, it is not possible to link national statistics, as provided by the FAOSTAT database, to climate and soil data because the spatial distribution is unknown. The methodology described below generates land-use maps for any given African country on the basis of available data sets. The basis of the proposed methodology lies in the traditional qualitative land evaluation, where land qualities are matched with land-use requirements in order to find the suitability of land for different uses (FAO, 1976). The methodology for land-use mapping comprises three key steps:

Step 1: Identify land units with similar topography, climate and soil conditions.
Step 2: Match properties of the land units with crop requirements.
Step 3: Disaggregate harvested areas from FAOSTAT over the land units.

Step 1

The first step identifies land units defined by topography, soil and climate. Topography is described by a global 30-arc second digital elevation model (DEM)

GTOPO30 (USGS, 1998). The 1:5 000 000 FAO soil map of the world describes the soils (FAO/UNESCO, 1997). However, the legend of the soil map indicates the soil classification and does not provide quantitative estimates of soil properties. Batjes (2002) developed the world inventory of soil emission potentials (WISE) database that provides quantitative estimates of soil properties for all the soil classes of the FAO soil map of the world. For climate, this study used the global climate database compiled by the International Institute for Applied Systems Analysis (IIASA), as developed by Leemans and Cramer (1991). The global AEZs (FAO and IIASA, 2000) provided information about the length of the growing period as a function of weather conditions. However, such an evaluation is only useful where the area is actually being cropped or grazed. The United States Geological Survey (USGS), the University of Nebraska-Lincoln (the United States of America), and the European Commission's Joint Research Centre have carried out a global land cover assessment using two subsequent satellite images (USGS *et al.*, 2000). This study used the 'seasonal land cover region' legend, reclassified into eight main classes. All areas under agriculture were reclassified as cropland or mixed cropland / natural vegetation.

The maps were projected using a Lambert azimuthal equal-area projection with a central meridian at 20° and a reference latitude of 5°. The next step was to convert the maps to a 1-km grid (where necessary) before overlaying them onto a single 1-km grid. These maps contained data on altitude, soils, climate, growing period and land cover. By linking the databases it was possible to create a table with the following land characteristics: land cover, length of growing period, rainfall, temperature, soil depth, texture, drainage and altitude.

Step 2

The second step includes the traditional matching process, as per the FAO qualitative land evaluation system (FAO, 1976), which compares land qualities with crop requirements. However, lack of available data at this scale level did not allow for an assessment of land qualities. Therefore, the available land characteristics as listed above formed the basis for the evaluation. The crop environment response database ECOCROP (FAO, 1998a) describes crop requirements, expressed in the same way as land characteristics. ECOCROP provides information on crop requirements for 1 710 different crops, grasses and trees. For many crop requirements, the database provides minimum and maximum values as well as optimal ranges.

A program developed in Delphi matches the land units with the 32 main crops and fallow described in the FAOSTAT database through the respective land characteristics and crop requirements. The result of the matching process is a six-digit code that represents the classification of the six key land characteristics from 1 (not suitable) to 3 (suitable) as illustrated in Figure 8. The code lists the land characteristics in sequence from highly important (left) to less important (right). Thus, it is possible to sort the suitability codes and obtain an automatic ranking of the likelihood of finding a specific form of land use on the land unit.

Step 3

The final step of the procedure is to allocate the crops according to the suitability classification. The FAOSTAT database provided the actual areas of each crop. This database contains national data on the harvested areas for the most important agricultural crops. A predefined crop order file determines the order in which crops are allocated. This study ranked crops mainly on the basis of their economic importance (Table 8), i.e. it allocated an important cash crop such as tea to the most suitable locations and a less important food crop such as millet to less suitable places. Each crop is distributed to the areas with the highest suitability for that specific crop, unless other crops already fill the area. This means that crops that are high in the crop order are allocated to the most suitable places. An exception was fallow, because fallow depends not on suitabilities but on the character of a particular land-use system. Therefore, the fallow area was split and allocated by ratio to those crops related with fallow systems, which are mainly cereals and root crops. This adaptation delivered a more realistic pattern for the fallow areas, where fallow is located in

FIGURE 8
Code for land suitability

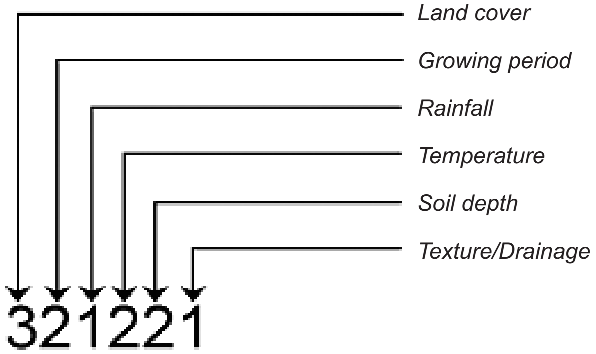


TABLE 8
Crop order for the land-use-map procedure

Ghana	Kenya	Mali
Oil-palm	Tea	Rice
Coffee	Coffee	Vegetables
Cotton	Vegetables	Fruits other
Rubber	Cotton	Tobacco
Tobacco	Potato	Tea
Coconut	Citrus	Cotton
Citrus	Fruits other	Sugar cane
Vegetables	Coconut	Fibres
Fruits other	Sugar cane	Sweet potato
Sugar cane	Rice	Wheat
Rice	Tobacco	Maize
Banana	Sunflower	Cereals other
Plantain	Sesame	Cassava
Cocoa	Plantain	Roots other
Sweet potato	Banana	Millet
Roots other	Roots other	Sorghum
Cassava	Sweet potato	Pulses
Millet	Wheat	Groundnut
Sorghum	Maize	
Maize	Barley	
Pulses	Cassava	
Groundnut	Millet	
	Sorghum	
	Pulses	
	Groundnut	

the same area as the crops of that particular land-use system. It was not possible to simulate directly short-distance variation in cropping systems or multiple cropping. This is because only one land use can be allocated to each grid cell. However, by aggregating the final results to a larger grid size, these systems were taken into account indirectly. It was possible to link the resulting output table of the simulation to the original grid map, and the land-use map showed the most likely distribution of crops, based on suitabilities.

Model parameters

IN1: Mineral fertilizer

The input of mineral fertilizer was calculated per crop. Each crop was given a fraction of the total fertilizer nutrient consumption. The fractions were based on data of the fertilizer-use-per-crop studies of the International Fertilizer Industry Association (IFA), the International Fertilizer Development Center (IFDC) and FAO (IFA/IFDC/FAO, 2000). These data were not available for every country. For Ghana and Mali, this study used data from surrounding countries within the same AEZ. The total fertilizer consumption per country was taken from the FAOSTAT database. The program MS Access then calculated the average amount of fertilizer per crop in terms of kilograms per hectare.

Example calculation

For a 'maize' grid cell in Kenya, the calculations were:

IN1_N = 0.274 × 52 733 000 / 1 433 333 = 10.1 kg N/ha
IN1_P = 0.255 × 30 638 000 / 1 433 333 = 5.5 kg P/ha
IN1_K = 0.000 × 11 667 000 / 1 433 333 = 0 kg K/ha
0.297 = factor of total N consumption applied to maize
0.255 = factor of total P consumption applied to maize
0.000 = factor of total K consumption applied to maize
52 733 000 = total N fertilizer consumption (kg)
30 638 000 = total P fertilizer consumption (kg)
11 667 000 = total K fertilizer consumption (kg)
1 433 333 = total harvested area of maize (ha).

TABLE 9
Number of animals per country

Animals	Ghana	Kenya	Mali
Asses	14 000	-	666 000
Camels	-	801 000	417 000
Cattle	1 274 000	13 269 000	6 122 000
Chickens	17 333 000	29 885 000	24 500 000
Goats	2 768 000	10 433 000	8 939 000
Horses	2 900	2 000	150 000
Pigs	346 000	302 000	65 000
Sheep	2 547 000	7 800 000	6 057 000

Source: FAOSTAT.

IN2: Organic inputs

Livestock density maps developed by FAO and the environmental research group of Oxford Limited (Figure 9) (FAO, 2000) were available for the major livestock classes, i.e. cattle, small ruminants and poultry (Table 9). The poultry density map was based on the rural population of SSA (FAO, 2001b). The number of poultry was presumed to have the same spatial distribution as the rural population. The livestock densities were multiplied by the excretion per animal per year (Table 10) and the nutrient content of the manure (Table 11). This generated the total amount of nutrients produced per livestock class. Annex 9 gives the literature sources for the nutrient values used.

FIGURE 9

Cattle density map of Africa

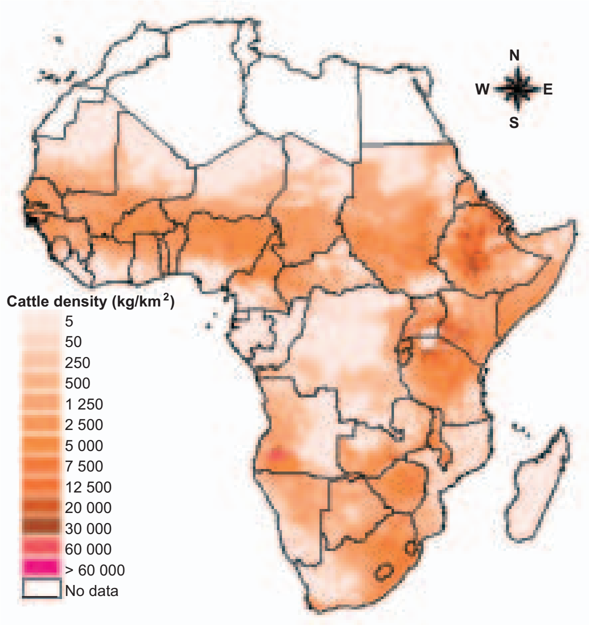


TABLE 10

Excretion

	Per day	Per year
	(kg fresh matter per kg body weight)	
Cattle	0.0170	6.20
Poultry	0.0214	7.80
Sheep/goat	0.0198	7.22

Source: Derived from Fernandez-Rivera *et al.* (1995).

TABLE 11

Nutrient content of manure (fresh weight)

	N	P	K
		(%)	
Cattle manure	0.76	0.15	0.67
Poultry manure	1.08	0.39	0.35
Sheep/goat manure	0.79	0.20	0.50

Source: Derived from sources in Annex A.

Although the total amount of nutrients produced by livestock is known, the losses and their distribution remain undetermined. According to Fernandez-Riviera *et al.* (1995) and Schlecht *et al.* (1995), animals produce 43 percent of their manure at night in their stable/corral/boma. Thus, 57 percent of the manure, losses excluded, remains in the field (grid cell). The other 43 percent, losses excluded, might be relocated to specific crops and fields. Moreover, such a study as the present one should consider livestock from grid cells without crops. This is because livestock relocates nutrients from pastureland to the stable and afterwards to the crops. Therefore, the livestock density maps were aggregated to a 30-km grid, which represents the average manure availability in a region. This average amount was multiplied by an aggregation factor and a crop factor. The aggregation factor was country dependent and related to the population density. This factor was 2 for Ghana and

Mali, and 1.5 for Kenya, because of the greater population density. The crop factor determines whether a specific crop receives manure (1), twice as much manure (2), or no manure (0). Annex 7 presents the estimates of these factors for each country.

During grazing, manure is lost along roadsides and other places where no crops are growing. These losses were estimated at 15 percent for all countries. The losses during storage are probably larger because manure also has other uses, such as fuel and house construction material. Losses also occur during storage and manifest themselves through leaching, denitrification and volatilization. A factor for such losses depends considerably on the type of management, and different factors were used for each country. The estimated losses for Ghana, Mali and Kenya were 40, 25 and 15 percent, respectively. These percentages were based on population density, livestock system and the relative importance of manure as a fertilizer. Manure is not collected as intensively in Ghana as in Kenya because livestock is not as important and the population density is lower. Kenya has more 'semi-grazing' and 'zero-grazing' systems, while Ghana and Mali have mainly 'free range' systems. For the calculated manure application, the losses due to leaching, denitrification and volatilization were calculated in OUT3 and OUT4.

Summary of calculation procedure per grid cell

IN2 = livestock density × factor manure × factor management (during grazing) + livestock density aggregated × factor manure × factor management (application from bomas, etc.);

livestock density: in kilograms per square kilometre, derived from livestock atlas;

factor manure: excretion and nutrient content factor (Tables 10 and 11);

factor management: crop and country dependent factor (from literature, experts), indicates time of grazing, manner of application and losses.

This calculation was performed for each livestock group (cattle, small ruminants and poultry) and these values were summed.

Example calculation

For a 'maize' grid cell in Kenya and a cattle density of 100 kg/ha (about 50/km^2) the calculations were:

$IN2_N$ = 100 × 6.20 × 0.0076 × 0.57 × 0.85 + 120 × 1.5 × 2 × 6.20 × 0.0076 × 0.43 × 0.80 = 8.1 kg N/ha

$IN2_P$ = 100 × 6.20 × 0.0015 × 0.57 × 0.85 + 120 × 1.5 × 2 × 6.20 × 0.0015 × 0.43 × 0.80 = 1.6 kg P/ha

$IN2_K$ = 100 × 6.20 × 0.0067 × 0.57 × 0.85 + 120 × 1.5 × 2 × 6.20 × 0.0067 × 0.43 × 0.80 = 7.1 kg K/ha

100 = cattle density (kg/ha)

6.20 = cattle excretion factor in kilograms fresh manure per kilogram body weight per year

0.0076 = N content of fresh cattle manure

0.0015 = P content of fresh cattle manure
0.0067 = K content of fresh cattle manure
0.57 = factor for manure produced during grazing
0.85 = factor corrected for losses along roadsides, etc.
120 = aggregated cattle density (kg/ha), represents average amount of manure in region
1.5 = country aggregation factor
2 = factor for redistribution to maize (relatively more manure to maize than other crops)
0.43 = factor for manure produced in bomas, etc. (at night)
0.80 = factor corrected for storage losses, etc.

IN3: Wet and dry deposition

The input of nutrients by deposition consists of two parts: wet deposition related to rainfall; and dry deposition related to Harmattan dust. Factors for nutrient contents were calculated based on literature values (Tables 12 and 13). A map with Harmattan dust deposition values was created by interpolation, based on several literature sources (Table 14) and wind-stream patterns (Pye, 1987; McTainsh, 1980; McTainsh and Walker, 1982; Kalu, 1979). Figure 10 provides the details. The amount of dust was derived from this map, whereas the amount of precipitation was derived from the IIASA rainfall map (Leemans and Cramer, 1991).

Example calculation

For a grid cell in Ghana with 1 200 mm of rainfall and 80 kg of Harmattan dust per hectare, the calculations were:

$IN3_N$ = $0.00488 \times 1\,200 + 0.0038 \times 80 = 6.2$ kg N/ha
$IN3_P$ = $0.00063 \times 1\,200 + 0.00079 \times 80 = 0.8$ kg P/ha

TABLE 12
Nutrient content of rainwater

Location	N	P	K	Source
	(g/ha/mm rainfall)			
Côte d'Ivoire	1.54	0.01	1.17	Stoorvogel *et al.*, 1997b
Tropical world, average	3.94	0.38	3.07	Bruijnzeel, 1990
Bujumbura, Burundi	10.90	1.10		Langenberg *et al.*, 2002
Kigoma, Tanzania	3.80	0.40		Langenberg *et al.*, 2002
Mpulungu, Zambia	6.00	0.50		Langenberg *et al.*, 2002
Nigeria (average)	4.28			Jones and Bromfield, 1970
Côte d'Ivoire	3.45		1.90	Baudet *et al.*, 1989
Addis-Ababa, Ethiopia	7.08			Richard, 1963
Korhogo, Côte d'Ivoire	9.04	0.96	3.04	Pieri, 1985
Saria, Burkina Faso	6.28	2.44	3.95	Pieri, 1985
Senegal	0.60	1.56	4.90	Pieri, 1985
Yangambi, Congo	3.47			Meyer and Pampfer, 1959
Average	4.88	0.63	2.63	
Standard deviation	2.47	0.55	1.10	

TABLE 13
Nutrient content of Harmattan dust

Location	N	P	K	Source
		(g/kg dust)		
Nigeria		0.7	17.0	Pye, 1987
Kano, Nigeria	3.7	1.1	24.6	Pye, 1987
Kano, Nigeria	3.4	1.0	23.9	Pye, 1987
Zaria, Nigeria	4.7	0.8	27.2	Pye, 1987
Zaria, Nigeria	3.3	0.8	24.6	Pye, 1987
Côte d'Ivoire		1.4	31.3	Stoorvogel *et al.*, 1997a
Sadore, Niger			1.2	Drees *et al.*, 1993
Chikal, Niger			0.7	Drees *et al.*, 1993
Northern Nigeria		0.1	1.5	Moberg *et al.*, 1991
Average	3.8	0.8	18.7	
Standard deviation	0.6	0.4	12.4	

TABLE 14
Amount of Harmattan dust at various locations

Location	Dust (kg/ha)	Source
Nyankpala, Ghana	185	Tiessen *et al.*, 1991
Kano, Nigeria	386	McTainsh and Walker, 1982
Maidugari, Nigeria	324	McTainsh and Walker, 1982
Zaria, Nigeria	106	McTainsh and Walker, 1982
Jos, Nigeria	21	McTainsh and Walker, 1982
Sokoto, Nigeria	15	McTainsh and Walker, 1982
Kano, Nigeria	1 000	McTainsh, 1980
Sadore, Niger	1 640	Drees *et al.*, 1993
Chikal, Niger	2 120	Drees *et al.*, 1993
Tai, Côte d'Ivoire	80	Stoorvogel *et al.*, 1997a

$IN3_K$ = 0.00263 × 1 200 + 0.0187 × 80 = 4.7 kg K/ha
0.00488 = N content of rain (kg N/ha per mm rainfall)
0.00063 = P content of rain (kg P/ha per mm rainfall)
0.00263 = K content of rain (kg K/ha per mm rainfall)
1 200 = rainfall (mm)
0.0038 = N content of Harmattan dust (kg N/kg dust)
0.00079 = P content of Harmattan dust (kg P/kg dust)
0.0187 = K content of Harmattan dust (kg K/kg dust)
80 = amount of Harmattan dust (kg/ha).

IN4: N fixation

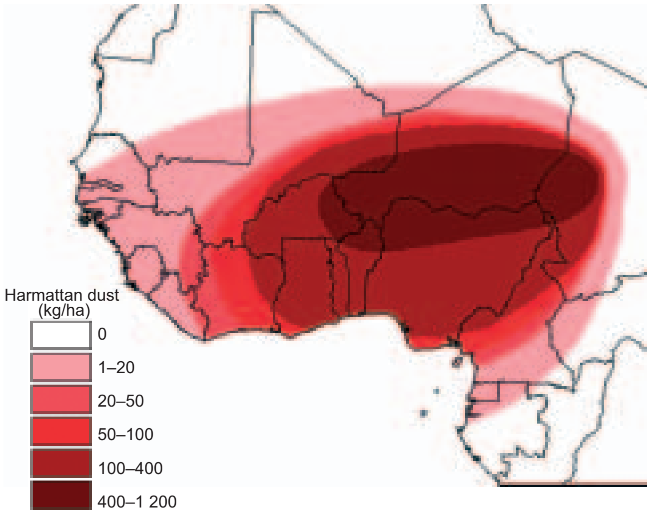
Input by BNF consists of different parts, i.e. symbiotic N fixation by leguminous crops, non-symbiotic N fixation and N-fixing trees. From the literature (Giller, 2001; Danso, 1992; Giller and Wilson, 1991; Hartemink, 2001), the percentages of total N uptake derived from symbiotic N fixation were:

- Groundnut - 65 percent;

- ➢ Soybean - 67 percent;
- ➢ Pulses - 55 percent;
- ➢ Sugar cane - 17 percent.

FIGURE 10

Distribution of Harmattan dust in West Africa



For wetland rice, cyanobacteria fix N, and this study used a value of 15 kg N/ha per year. This value is somewhat lower than that estimated in many experiments but according to Giller (2001) the effect of the cyanobacteria is overestimated and it does not occur in all fields. This N fixation occurs only in wetland rice, but in Africa more than 50 percent of the rice area is upland rice. However, FAOSTAT does not differentiate between wetland and upland rice. Therefore, the amount of N fixation by cyanobacteria was multiplied by a factor for wetland rice. According to Nyanteng (1986) and the IPCC (1997), Ghana has 15 percent wetland rice, Kenya 25 percent and Mali 95 percent. Not much literature is available for non-symbiotic N fixation and N-fixing trees. This input was estimated on the basis of the amount of rainfall using the following equation (N fixed is expressed in kg N/ha and rainfall in mm/year):

$$\text{N fixed} = 0.5 + 0.1 \times \sqrt{\text{rainfall}}$$

Example calculation

For a 'groundnut' grid cell in Ghana with a rainfall of 1 000 mm and a yield of 1.2 tonnes/ha, the calculation was:

$IN4_N$ = $0.65 \times (1.2\times37.2+1.2\times15.9) + (0.5 + 0.1\times\sqrt{1\,000}) = 45.0$ kg N/ha
0.65 = factor for symbiotic N fixation of total N uptake
1.2 = yield (tonnes/ha)
37.2 = nitrogen content of crop product (kg N/tonne harvested product)
15.9 = nitrogen content of crop residue (kg N/tonne harvested product)
1 000 = annual rainfall (mm).

IN5: Sedimentation

This flow consists of two parts: nutrient input in irrigation water; and input in sediment as a result of erosion. FAO and the University of Kassel, Germany, have developed a worldwide map of irrigation areas (Döll and Siebert, 2000). The nutrient input was calculated by combining this map with the estimated amount of irrigation water, set at 300 mm/ha/year, and the nutrient content of irrigation water (N: 3.3 mg/litre, P: 0.43 mg/litre and K: 1.4 mg/litre) derived from Stoorvogel and Smaling (1990). The input by sedimentation was calculated by the "LandscApe ProcesS modelling at mUltidimensions and Scales" (LAPSUS) model (Schoorl *et al.*, 2000; Schoorl *et al.*, 2002), which also provided a feedback between IN5 and OUT5. Details are given under OUT5. The model output was the net sedimentation in metres. It was possible to convert this value into nutrient input by combining it with bulk density and nutrient content.

Example calculation:
For an 'irrigated rice' grid cell in Mali, in the absence of sedimentation, the calculations were:
$\mathrm{IN5}_{\mathrm{N}}$ = 300 × 3.3 × 0.01 = 9.9 kg N/ha
$\mathrm{IN5}_{\mathrm{P}}$ = 300 × 0.43 × 0.01 = 1.3 kg P/ha
$\mathrm{IN5}_{\mathrm{K}}$ = 300 × 1.4 × 0.01 = 4.2 kg K/ha
300 = amount of irrigation water in mm (fixed)
3.3 = N content of irrigation water (mg N/litre)
0.43 = P content of irrigation water (mg P/litre)
1.4 = K content of irrigation water (mg K/litre)
0.01 = conversion factor (1 mm = 10 litres/ha).

OUT1: Crop products

This study calculated the output of nutrients by crop products by multiplying yield by the nutrient content of the crops (Table 15). FAO statistics (FAOSTAT) provided data on harvested area, production and, hence, yield for each country.

Example calculation
For a 'maize' grid cell in Kenya, the calculations were:
$\mathrm{OUT1}_{\mathrm{N}}$ = 1.5 × 16.8 = 25.2 kg N/ha
$\mathrm{OUT1}_{\mathrm{P}}$ = 1.5 × 4.1 = 6.2 kg P/ha
$\mathrm{OUT1}_{\mathrm{K}}$ = 1.5 × 4.8 = 7.2 kg K/ha
1.5 = yield (tonnes/ha)
16.8 = N content of maize (kg N/tonne harvested product)
4.1 = P content of maize (kg P/tonne harvested product)
4.8 = K content of maize (kg K/tonne harvested product).

OUT2: Crop residues

This study calculated the output of nutrients in crop residues by multiplying crop residue yield by its nutrient content (Table 15) and adjusting this by a removal factor. The latter is crop and country specific, is based on scarce literature values and expert knowledge, and reflects the type of management. Removal factors for central Kenya, with a high population density and many animals, are larger than those for southern Ghana, where livestock are relatively unimportant. A special form of residue removal is 'burning', but it is difficult to determine its extent

TABLE 15

Nutrient content of harvested product, crop residues, and removal factors for crop residues

Crops	Harvested product			Crop residues			Removal factor		
	N	P	K	N	P	K	Ghana	Kenya	Mali
	(kg/tonne)			(kg/tonne)			(%)		
Banana	1.2	0.3	4.5	1.6	0.3	11.9	10	20	-
Barley	15.5	2.8	6.0	7.0	1	21.0	-	35	-
Cassava	4.2	0.5	4.3	4.6	0.9	1.4	40	20	20
Cereals other	16.7	4.4	4.8	10.9	2.3	38.6	-	-	60
Citrus	1.8	0.2	2.3	0.6	0.2	4.4	10	15	-
Cocoa	40.0	8.5	19.3	19.9	4.7	33.3	10	-	-
Coconut	61.0	7.2	9.8	27.0	5.7	25.3	10	20	-
Coffee	35.0	2.6	16.8	4.3	3.8	9.3	10	15	-
Cotton	18.7	9.7	9.0	13.9	6	29.8	60	60	60
Fibres	5.0	0.4	6.0	2.1	0.7	9.0	-	-	10
Fruits other	2.0	0.2	2.0	1.8	0.2	4.9	40	50	50
Groundnut	37.2	6.0	8.2	15.9	2.4	14.9	30	60	80
Maize	16.8	4.1	4.8	9.7	1.9	21.4	30	75	80
Millet	19.2	6.0	5.4	20.4	4	59.8	30	70	50
Oil crops other	2.6	0.5	4.4	0.3	0.6	5.4	-	-	-
Oil-palm	2.9	0.7	4.1	3.7	0.6	3.3	10	-	-
Plantain	0.7	0.1	3.4	1.2	0.3	6.4	10	20	-
Potato	4.4	1.3	6.9	2.3	0.7	4.5	-	20	-
Pulses	20	3.4	11.1	10.4	1	13.1	30	70	80
Rice	11.6	3.4	3.4	11.3	2.3	35.8	15	20	35
Roots other	4.6	0.3	2.9	1.9	0.5	3.1	25	20	25
Rubber	6.9	1.2	4.6	1.0	0.2	4.0	10	-	-
Sesame	30.0	6.1	6.8	15	5.4	21.1	-	75	-
Sorghum	14.5	5.5	3.8	10.8	4.6	29.2	30	70	50
Soybean	62.1	10.9	20.0	17.6	3.0	14.4	-	-	-
Sugar cane	0.6	0.2	1.2	0.3	0.3	0.3	10	20	20
Sunflower	24.0	3.5	5.5	23.0	3.2	41.3	-	40	-
Sweet potato	4.8	0.8	7.3	2.1	1.2	3.3	30	20	30
Tea	35.0	3.8	13.4	0.1	0	0	-	15	10
Tobacco	56.0	8.2	72.7	0.1	0	0.2	10	20	10
Vegetables	9.0	0.9	2.6	3.2	1.4	7.8	40	60	80
Wheat	22.3	4.3	5.8	4.3	1.8	26.7	-	60	40

at the macrolevel. Therefore, burning was considered solely for cotton, because farmers normally burn these residues in order to prevent pests and diseases. All N is lost by volatilization and an estimated 50 percent of all K is lost directly through leaching.

Example calculation

For a 'maize' grid cell in Kenya, the calculations were:

$OUT2_N$ = $1.5 \times 9.7 \times 0.75 = 10.9$ kg N/ha
$OUT2_P$ = $1.5 \times 1.9 \times 0.75 = 2.1$ kg N/ha
$OUT2_K$ = $1.5 \times 21.4 \times 0.75 = 24.1$ kg N/ha
1.5 = amount of residues (tonnes/ha)

9.7 = N content of maize residues (kg N/tonne harvested product)
1.9 = P content of maize residues (kg P/tonne harvested product)
21.4 = K content of maize residues (kg K/tonne harvested product)
0.75 = removal factor of crop residues for maize.

OUT3: Leaching

Leaching can be an important outflow for N and K. De Willigen (2000) developed a regression model to estimate the amount of leached N. This model is based on an extensive literature search and is valid for a wide range of soils and climates. A new regression model for K leaching was developed, based on the same data set:

$\text{N leaching} = (0.0463 + 0.0037 \times (P / (C \times L))) \times (F + D \times NOM - U)$
$\text{K leaching} = -6.87 + 0.0117 \times P + 0.173 \times F - 0.265 \times CEC$
P = annual precipitation (mm)
C = clay (percent)
L = layer thickness (m) = rooting depth, derived from FAO (1998b), see Annex 3
F = mineral and organic fertilizer nitrogen (kg N/ha)
D = decomposition rate (= 1.6 percent per year)
NOM = amount of N in soil organic matter (kg N/ha)
U = uptake by crop (kg N/ha)
CEC = cation exchange capacity (cmol/kg).

The N-leaching regression model is based on 43 different measurements and accounts for 67 percent of the variance (De Willigen, 2000). The equation was edited slightly for perennial crops by multiplying the amount of N in soil organic matter by 0.5. This prevented overestimation of N leaching, because perennials can take up N throughout the year. The K-leaching regression model is based on 33 representative experiments and has an R^2 value of 0.45 (Annex 2 for references).

Example calculation

For a ‘maize’ grid cell on a ferric Luvisol in Kenya, with a yield of 1.8 tonnes/ha and a fertilizer application of 50 kg N/ha and 30 kg K/ha, the calculations were:

$OUT3_N = (0.0463 + 0.0037 \times (1\,500/(21.3 \times 0.9))) \times (50 + 0.016 \times 2\,418 - 1.8 \times (16.8 + 9.7)) = 13.8$ kg N/ha
$OUT3_K = -6.87 + 0.0117 \times 1\,500 + 0.173 \times 30 - 0.265 \times 6.24 = 14.2$ kg K/ha
1 500 = rainfall (mm)
21.3 = clay content (percent)
0.9 = layer thickness is rooting depth of maize (m)
50 = N fertilizer application (kg N/ha)
0.016 = decomposition rate (per year)
2 418 = amount of soil nitrogen in upper 20 cm (kg N/ha)
1.8 = yield of maize (tonnes/ha)
16.8 = N content of crop product (kg N/tonne harvested product)
9.7 = N content of crop residue (kg N/tonne harvested product)

30 = K fertilizer application (kg K/ha)
6.24 = CEC (cmol/kg).

OUT4: Gaseous losses

Two processes cause the bulk of gaseous N emissions: denitrification and volatilization. Denitrification takes place under anaerobic conditions but soil does not have to be fully saturated for denitrification to occur. A moist soil loses nitrates through microbial processes in wet films and pockets. The expectation is for losses through denitrification to be greatest in wet climates, on highly fertilized and clayey soils. Ammonia (NH_3) volatilization plays a role mainly in alkaline soils, but such soils are not very common at the macrolevel in SSA. Therefore, volatilization and denitrification in soils do not receive separate treatment. Volatilization is also linked directly to the amount of mineral and organic fertilizer.

This study developed a regression model to estimate gaseous N losses. The equation consisted of two parts: one regression model for the N_2O and NO_x losses through denitrification, and a direct loss factor for volatilization of NH_3. The equations were based on literature data for tropical environments (Annex 4). These were derived from a larger data set compiled for a recent study to estimate global gaseous emissions of NH_3, NO and N_2O from agricultural land (IFA/FAO, 2001). The N_2O regression model was based on a data set of 80 experiments and had an R^2 value of 0.45. The NO_x regression model was based on 36 different measurements and had an R^2 value of 0.91. For NH_3 emissions, 73 measurements were available. Of all fertilizer N applied, 11.3 percent is lost, with a standard deviation of 6.2 percent.

$OUT4 = (0.025 + 0.000855 \times P + 0.01725 \times F + 0.117 \times O) + 0.113 \times F$
P = annual precipitation (mm)
F = mineral and organic fertilizer nitrogen (kg N/ha)
O = organic carbon content (percent).

Example calculation

For a 'maize' grid cell with a ferric Luvisol in Kenya, with a mineral and organic fertilizer application of 50 kg N/ha, the calculation was:

$OUT4_N = (0.025 + 0.000855 \times 1\,500 + 0.01725 \times 50 + 0.117 \times 0.63) + (0.113 \times 50) = 7.8$ kg N/ha
1 500 = rainfall (mm)
0.63 = organic carbon content (percent)
50 = mineral and organic N fertilizer application (kg N/ha).

OUT5: Erosion

Erosion is difficult to estimate, yet it can be important. To estimate erosion, this study utilized the LAPSUS model. This model simulates the amount of erosion and sedimentation at the landscape scale. This method has several advantages: it generates quantitative data; it considers erosion at the landscape scale; and it takes sedimentation into account. This is preferable to literature estimates, because the latter rely mainly on plot experiments, which are not representative for the macrolevel.

Basic concepts

This study used a modelling approach based on work by Kirkby (1971; 1978; 1986) and Foster and Meyer (1972; 1975). They assume the potential energy content of flowing water over the landscape surface as the driving force for sediment transport. Another important assumption is the use of the continuity equation for sediment movement. This states that the difference between sediment input and output equalizes the net increase in storage. Assuming quasi-steady state, Foster and Meyer (1972; 1975) formulated down-slope sediment transport continuity as:

$$-\frac{\partial z}{\partial t} = \frac{C - S}{h}$$

where z is elevation (m), t stands for time, C is sediment transport capacity (m^2/time), and S is the sediment transport rate (m^2/time). Term h stands for detachment rate under erosion conditions, while it represents the settlement rate under sedimentation conditions. To estimate the change in elevation δz over time step δt, it is necessary to calculate the changes in the sediment transport rate δS. These changes in the rate of transport are controlled by the transport capacity C, where the capacity excess will be filled by detachment of sediment (e.g. erosion, surface lower), and a capacity deficit will lower the amount of sediment in transport (e.g. sedimentation, surface higher). According to Foster and Meyer (1972; 1975), after integration, assuming that transport capacity and detachment or settlement capacity remain constant within one finite element, the calculation for the rate of sediment in transport is:

$$S = C + (S_0 - C) \cdot e^{-dx/h}$$

where the transport rate S (m^2/time) over the length dx of a finite element is calculated as a function of transport capacity C (m^2/time) and detachment rate or settlement rate h compared with the amount of sediment already in transport S_0 (m^2/time). S is expressed as soil volume per unit grid width per year. To convert to erosion or deposition rate in mass per area per year, S is divided by the grid length (dx) and multiplied by soil bulk density. Term h (m) refers to the transport capacity divided by the detachment capacity (m/time) (C/D) or to the transport capacity in proportion to the settlement capacity (-m/time) (C/T). Implementation of this equation will need expressions for transport capacity C, detachment capacity D and settlement capacity T. These capacities are calculated as functions of discharge and slope, which gives:

$$C = \alpha \cdot Q^m \cdot \Lambda^n$$

where C is calculated as a function of discharge Q (m^2/time) and slope tangent ($\delta z/\delta x$) Λ [-], m and n are constants (dummy variable α corrects the units). Assuming, *inter alia*, that detachment and settlement capacity are proportional to a certain shear and that the drag coefficient is constant, the equations are:

$$D = K_{es} \cdot Q \cdot \Lambda$$

$$T = P_{es} \cdot Q \cdot \Lambda$$

where K_{es} is a lumped surface factor (per metre) indicating the erodibility of the surface and P_{es} a similar factor indicating lumped sedimentation characteristics (per metre). The erosion conditions for D or sedimentation conditions for T will result in opposite signs for the change in S and as a result also δz.

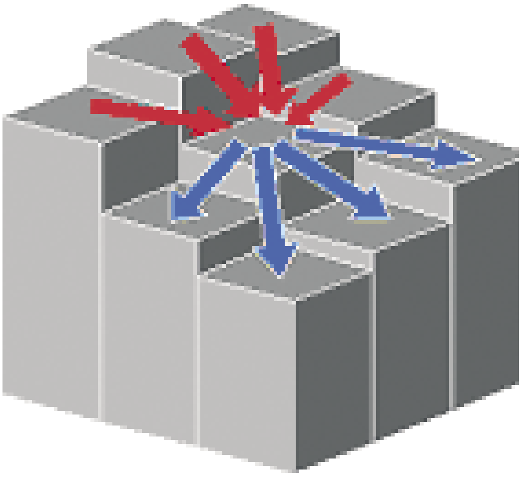
Model structure and flow routing

LAPSUS is based on a grid structure of square cells of equal size. Each cell presents a generalized part of the landscape that can comprise several unique characteristics (altitude, soils, etc.). The model is structured in a way that is optimal for the simulation of both two-dimensional and three-dimensional characteristics in the time dimension. In this way, the model considers the evaluation of capacities as a two-dimensional process because only the gravitational force and water flow downslope within a finite element are used. However, for the estimation and routing of the incoming and outgoing water and sediment fluxes, the model evaluates the results of surrounding grid cells within the whole three-dimensional landscape. The finite element methodology implies variable length but a unit width at different resolutions for each element.

Landscape process modelling

The LAPSUS model evaluates the rates of sediment transport by calculating the transport capacity of water flowing downslope from one grid cell to another as a function of the discharge and the gradient of the slope. A surplus of the transport capacity of the water is filled by the detachment of sediment, which depends on the erodibility, K_{es} (per metre), of the surface. This detachment of sediment provokes lowering of the surface or erosion. However, when the rate of sediment in transport exceeds the local capacity, e.g. because of lower gradients, a settlement function will deposit the surplus of sediment in transport, thereby causing a higher surface or sedimentation. The routing of the overland flow and the resulting model calculations are done with a multiple flow algorithm in order to enable a better representation of divergent properties of the convex topography (Figure 11). The modelling framework underwent elaborate testing for the effects of changing flow algorithms, spatial resolution and temporal resolution. LAPSUS has only been validated for its base scenario by field observations in southern Spain, but it displays erosion and sedimentation patterns which match closely with real world erosion and sedimentation patterns at the same spatial resolution.

FIGURE 11
Schematic representation of a multiple flow algorithm



The main input parameters for the grid-based LAPSUS model are the topographical potentials (slope gradients) from a DEM and the evaluation of the rainfall surplus that will generate the overland flow. The assumption is one of uniform conditions for all involved parameters within each grid cell. The model will evaluate all considered parameters on an annual basis for a certain run of time. Other input parameters are soil depth, to estimate the amount of infiltration, and erodibility (K_{es}). It is possible to determine these parameters from a geology or soil map. Moreover, a land use or land cover map can serve as input for the estimation of the amount of runoff. The LAPSUS model can now run for the chosen number of years and input parameters.

The present study used the following input data:

- ➢DEM with a resolution of 1 km (USGS, 1998);
- ➢land cover map (USGS *et al.*, 2000);
- ➢rainfall map (Leemans and Cramer, 1991) and data for Kenya (Corbett and White, 1998);
- ➢soil erodibility (K factor), derived from soil map of the world (FAO/UNESCO, 1997);
- ➢soil depth, derived from soil map of the world (FAO/UNESCO, 1997).

Annex 5 describes the exact procedure and factors used for the model.

The outcome of the model is a net erosion-sedimentation map with units in metres, convertible to tonnes per hectare (Figure 12). It is possible to calculate the loss or gain of nutrients by multiplying by soil nutrient contents and an enrichment factor. The enrichment factor reflects the fact that the finer and more nutrient-rich soil particles will be dislodged earlier during erosion. Based on literature data, the study used the following enrichment factors: 2.3 for N, 2.8 for P, and 3.2 for K (FAO, 1984; FAO, 1986 and Khisa *et al.*, 2002). It is possible to derive the nutrient content of the soil from the soil map. As a result of erosion, the rooting depth zone is extended, which means that new nutrients come within reach of plant roots. This study assumed that 25 percent of P and K, which is lost due to erosion, was gained at the rooting zone through this process.

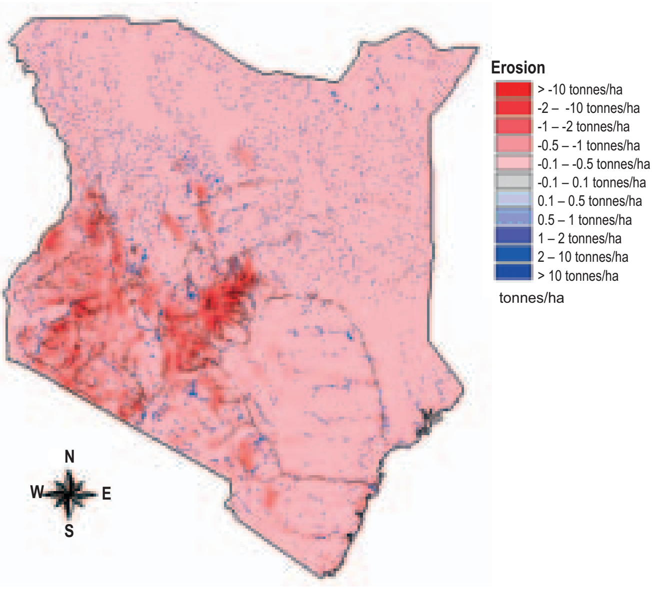
Example calculation

For a grid cell on a ferric luvisol in Kenya, with 1 mm erosion, the calculations were:

$OUT5_N$ = 0.001 × 1.55 × 0.078 × 2.3 × 100 000 = 27.8 kg N/ha
$OUT5_P$ = 0.001 × 1.55 × 0.0068 × 2.8 × 0.75 × 100 000 = 2.2 kg P/ha
$OUT5_K$ = 0.001 × 1.55 × 0.016 × 3.2 × 0.75 × 100 000 = 6.0 kg K/ha
0.001 = erosion (m)
1.55 = bulk density (kg/dm^3)
0.078 = soil N content (percent)
0.0068 = soil P content (percent)
0.016 = soil K content (percent)
2.3 = enrichment factor for N
2.8 = enrichment factor for P
3.2 = enrichment factor for K
0.75 = factor for rootzone extension
100 000 = conversion factor to kg/ha.

FIGURE 12

Erosion-sedimentation map for Kenya



Fallow

The FAO statistics did not provide details on the area under fallow. However, it was possible to calculate it indirectly by subtracting the total sum of harvested areas from the total arable land (Table 16). IN1 and OUT1 are not relevant for fallow. IN2 and OUT 2 are related as they comprise grazing animals and the same defecating animals. It is not known whether IN2 should be larger or smaller than OUT2. Not all manure is left on the field (only about 57 percent), but on the other hand a lot of animal feedstuff is obtained from sources other than crop residues, and from roadside grazing. Hence, for fallow land the amount of nutrient

TABLE 16

Fallow area for Ghana, Kenya and Mali

	Arable land	Harvested area	Fallow
		(ha)	
Ghana	5 300 000	4 471 445	828 555
Kenya	4 520 000	3 604 198	915 802
Mali	4 650 000	3 247 573	1 402 427

Source: Derived from FAOSTAT.

input by manure (IN2) was presumed to be equal to the amount lost by grazing (OUT2). All other nutrient flows can be treated equally as for other crops.

MESOLEVEL

General procedure

The mesolevel nutrient-balance calculation utilized tabular data. The approach involved establishing relations between land use and soils in order to compensate for the lack of spatial data. For example, in Ghana, farmers grow cocoa mainly on top and slope positions, where orthic Acrisols are located. As it is easier to adapt tabular data rather than spatial data, it is possible to include exceptions. In particular, compared with the macrolevel, it enables an improved description of crop management data, which is very important at the mesolevel. It was not possible to create a reconnaissance or semi-detailed land-use map for the mesolevel study areas. Mesolevel data for a map-based procedure were not available and macrolevel data would have provided no added value and failed to be sufficiently representative. At the mesolevel, a 1-km grid is too coarse for representing physiographic differences with sufficient accuracy. If higher resolution data were available, it would be necessary to develop a new procedure for the creation of a land-use map. This is because a suitability approach is not appropriate at the mesolevel, where socio-economic factors are far more important. Aerial photographs and satellite images with fast field checks can also provide the basis for creating a land-use map. However, these were not available for the study areas. The data availability for the three countries was very different, which prohibited a generic approach at the mesolevel.

IN1 Mineral fertilizer

The sources of data on mineral fertilizer were farm surveys, recommended fertilizer rates and macrolevel data, depending on the data availability in each study area. Recommended fertilizer rates are generally much higher than the actual application rates because not all farmers wish or can afford to apply these quantities. Therefore, in order to prevent overestimation, the fertilizer rates were multiplied by a factor representing the ratio between the harvested area at the mesolevel and the harvested area at national level.

IN2 Organic fertilizer

The amount of available manure was derived from the number of livestock within the study area, using excretion, nutrient-content and nutrient-loss factors. The application per crop was derived from farm surveys or estimates. Local nutrient-content values were used where available.

IN3 Atmospheric deposition

The atmospheric deposition was derived from the macrolevel. Rainfall data from local weather stations were used or, where these were not available, they were derived from the macrolevel.

IN4 N fixation

Nitrogen fixation was treated in a way similar as that for the macrolevel. Where available, specific data related to N fixation should be included, e.g. agroforestry systems with N-fixing trees.

IN5 Sedimentation

Irrigation was not relevant for the three case-study areas. Sedimentation was estimated for river-valley crops, e.g. rice. The LAPSUS model was not used at the mesolevel because of the lack of spatial data.

OUT1 Crop products

Crop production data were multiplied by the nutrient contents of the crops. Where available, local nutrient-content factors were used because these can differ significantly from the average continental values used at the macrolevel.

OUT2 Crop residues

Crop-residue removal factors were derived from farm surveys or estimated by local experts. These factors were multiplied by the production and the nutrient-content factors of the crop residues.

OUT3 Leaching

The calculations of the leaching of N and K utilized the macrolevel regression models.

OUT4 Gaseous losses

The estimation of the gaseous N losses utilized the macrolevel regression model.

OUT5 Erosion

Estimates of erosion were made for each crop. These estimates took regional differences in topography and soils into account and were based on literature and expert knowledge. The LAPSUS model was not used because of the lack of spatial data.

Ghana

For Ghana, nutrient balances were calculated for two districts: Nkawie and Wassa Amenfi. The amount of data available in Ghana was small because there have been no studies on soil fertility and nutrient management in the cocoa area. Therefore, a significant amount of the data was derived from the macrolevel. A soil map (scale: 1:250 000) (Soil Research Institute, 1999) was available for both districts, but representative chemical characteristics of the soils were unknown. Therefore, the soil properties were derived from the WISE database (Batjes, 2002). Local weather stations were the source of the rainfall data, averaged for 1997–99. Nutrient balances were made for the following crops: cocoa, maize, cassava, plantain, cocoyam, yam, rice, vegetables and oil-palm. The area under annual

TABLE 17
Harvested areas and manure for each crop in two districts, Ghana

Crop	Nkawie District		Wassa Amenfi District	
	Area (ha)	% of manure	Area (ha)	% of manure
Cassava	11 838	15	7 700	15
Cocoa	48 493	0	240 961	0
Cocoyam	9 514	18	3 000	10
Fallow	14 600	0	7 300	0
Maize	11 455	50	5 650	40
Oil-palm	-	-	900	0
Plantain	11 725	15	5 000	10
Rice	1 462	0	2 112	0
Vegetables	-	-	250	20
Yam	1 175	2	1 500	5

crops and the macrolevel data provided the basis for estimating the area under fallow: 14 600 ha (13 percent) in Nkawie District, and 7 300 ha (2.7 percent) in Wassa Amenfi District. Annex 9 lists all the primary data.

IN1	No fertilizer data available. Macrolevel data used. Only data for cocoa available.
IN2	Livestock numbers known. Amount of available manure calculated. A loss factor of 50 percent was estimated because no active manure management takes place. Available manure allocated to crops as per Table 17.
IN3	Macrolevel data used.
IN4	No symbiotic and non-symbiotic N fixation according to the macrolevel equation.
IN5	Irrigation not relevant. For rice, estimated sedimentation rate: 1 mm/year.
OUT1	Production data available.
OUT2	Macrolevel crop residue removal factors used.
OUT3	Calculated according to the regression models.

TABLE 18
Estimated erosion per crop for cocoa-based system

Crop	Erosion (tonnes/ha)	Explanation
Cassava	5	Stands two years, but during harvest high erosion risk
Cocoa	1	On slopes, but thick litter layer and stable root system
Cocoyam	7	In fresh fields and high erosion risk during harvest
Fallow	0.5	Permanent ground cover
Maize	5	Planted in fresh bare fields
Oil-palm	1	Relatively flat areas and stable root system
Plantain	3	Relatively stable root system
Rice	0	In valleys and therefore no erosion, but sedimentation
Vegetables	10	Near houses, more runoff, more bare soil
Yam	7	In fresh fields and high erosion risk during harvest

OUT4 Calculated according to the regression model.
OUT5 Estimated values per crop used (Table 18).

Kenya

Many data were available for Kenya because it has been the subject of many soil fertility and nutrient management studies. However, not all of the data were useful because they were very scattered or based on only a few farms. The study area comprised the tea–coffee–dairy zone of Embu District, defined mainly by AEZ2 of the VARINUTS study (SC-DLO *et al.*, 2000). The area consists mainly of Nitisols. A soil map of Embu District (Ministry of Agriculture, 1987) was available, but only one soil type was differentiated within the study area. This study utilized the soil properties as determined in the VARINUTS study (Table 19). Annex 9 lists all the primary data.

TABLE 19
Soil properties for the upper AEZs in Embu District

Soil properties	AEZ1	AEZ2	AEZ3
pH	4.4	4.5	4.5
N total (%)	0.75	0.64	0.44
C total (%)	3.3	2.5	2.3
P total (ppm)	2 211	2 095	1 898
P Olsen (ppm)	3.5	2.9	2.3
K exch. (cmol/kg)	0.46	1.14	1.05
Bulk density (kg/dm^3)	0.80	1.20	1.55
Clay (%)	35	60	70
CEC (cmol/kg)	28.7	19.4	19.4

Source: Stoorvogel *et al.* (2000).

The nutrient balance was calculated for the following crops within the study area: tea, coffee, maize, beans, Napier grass, sorghum, cowpeas, cassava, potatoes, sweet potatoes and arrow roots. No data were available for Napier grass, so the study used a yield estimate of 35 tonnes/ha (Van den Bosch *et al.*, 1998b), and for the harvested area a value of 3 percent of the total cultivated area was taken (Abdullahi *et al.*, 1986). The fallow area was based on the non-cultivated area for the Manyatta and Nembure division, which is 24 km^2. Of this area, 75 percent was estimated as fallow, the remaining area as buildings and forest. The resulting fallow area was 1 800 ha, which is 8 percent of the total cultivated area. The estimated production of fallow land was 10 tonnes/ha, of which 5 percent was removed for fodder and firewood.

IN1 Mineral fertilizer application based on Staverman (2003) for several crops (data were derived from 50 farm interviews in AEZ3 of Embu District). Recommended mineral fertilizer rates used for other crops (Table 20).
IN2 Number of livestock known; amount of available manure calculated. Loss factor: 25 percent. Application factors based on Staverman (2003).
IN3 Dry deposition not relevant; macrolevel data used for wet deposition.
IN4 Symbiotic N fixation for beans, cowpeas and soybeans and non-symbiotic according to macrolevel equation.
IN5 Irrigation not relevant; sedimentation occurs only in the flood lakes.
OUT1 Production data available; local nutrient content factors of Van den Bosch *et al.* (1998) used.
OUT2 Estimates for local crop-residue removal factors used.
OUT3 Calculated according to the regression models.
OUT4 Calculated according to the regression model.

TABLE 20
Mineral fertilizer application rates, Embu District

Crop	N	P	K	Reference
	(kg/ha)			
Arrow roots	0	0	0	No fertilizer
Beans	6	6	0	Staverman, 2003
Cassava	0	0	0	No fertilizer
Coffee	59	13	0	Staverman, 2003
Cowpeas	0	40	0	Recommended (200 kg/ha, TSP)*
Fallow	0	0	0	No fertilizer
Maize	18	8	2	Staverman, 2003
Napier	33	6	0	Staverman, 2003
Potatoes	45	50	0	Min. of Agr. and GTZ, 1998 (250 kg/ha, DAP)
Sorghum	10	4	0	Recommended (50 kg/ha, 20:20:0)*
Sweet potatoes	17	7	14	Recommended (100 kg/ha, 17:17:17)*
Tea	34	3	6	Recommended (135 kg/ha, 25:5:5)*

TABLE 21
Estimated erosion per crop, Embu District

Crops	Erosion	LEINUTS	Explanation
	(tonnes/ha)		
Arrow roots	0	-	Grown in valleys, equilibrium expected
Beans	7	7.2	According to LEINUTS study
Cassava	10	-	Many erosion during harvest
Coffee	5	3.6	According to LEINUTS study
Cowpeas	7	-	Similar to beans
Fallow	0.5	0.6	According to LEINUTS study
Maize	8	8.1	According to LEINUTS study
Napier	4	4.6	According to LEINUTS study
Potatoes	3	2.6	According to LEINUTS study
Sorghum	8	-	Similar to maize
Sweet potatoes	5	4.3	According to LEINUTS study
Tea	1	0.8	According to LEINUTS study

* Recommended fertilizer rates based on Ministry of Agriculture (1997–2001).

OUT5 Estimated values per crop, based on data from the LEINUTS study (De Jager *et al.*, 2001) in Nyeri District, which is the same AEZ (Table 21).

Mali

For Mali, the nutrient-balance calculation considered the CMDT Koutiala Region in Mali-Sud. The CMDT has undertaken many farm surveys in this area, which have also generated a lot of data relating to nutrient management. Therefore, a lot of high-quality data for important flows, such as mineral fertilizers, organic fertilizers and crop-residue removal, were available for this study area. However, spatial data were practically non-existent, only one handdrawn morphological map of the region was usable. The cultivated areas lie on the lower slopes with three different soil types, depending on the parent material (Sissoko, 1999). The study used an average of the soil properties of these soils (Table 22). The main

TABLE 22

Soil properties for the lower slopes in Koutiala Region

Parent material	Sandstone	Schist	Dolerite	Average
Clay (%)	5.4	6.0	6.9	6.1
OM (%)	0.6	0.5	0.7	0.6
CEC (cmol/kg)	3.0	4.3	6.0	4.4
pH	5.5	5.8	5.6	5.6
N total (%)	0.03	0.04	0.03	0.03
P total (ppm)	93	139	97	110
P ass. (ppm)	5.7	3.0	3.5	4.1
K exch. (cmol/kg)	0.03	0.03	0.03	0.03

Source: Bitchibaly *et al*. (1995).

crops in the study area are: cotton, maize, sorghum, millet, rice, groundnut and cowpea. These crops account for 97 percent of the total cultivated area. Research in two representative villages provided the basis for the estimate of the fallow area (Kanté, 2001). In these villages, 48 percent of the cultivated area was under fallow. The resulting estimate for the whole of Koutiala Region is a fallow area of 227 200 ha. Annex 9 lists all the primary data.

IN1	Fertilizers applied: urea (46 percent N), cotton complex (14:9.6:10) and cereal complex (15:6.5:12.5). The amount of applied fertilizers per crop and percentage of fertilized fields was known (CMDT/SE, 1998, 1999, 2000).
IN2	Data on organic fertilizer application available (SEP, 1997, 1998, 1999).
IN3	Dry deposition and rainfall derived from the macrolevel.
IN4	Symbiotic N fixation for groundnut (65 percent) and cowpea (55 percent) and non-symbiotic according to the macrolevel equation.
IN5	Irrigation not relevant; sedimentation estimated at 1 mm/year for rice (grown in river valleys).
OUT1	Production data available; local nutrient content factors of Kanté (2001) used.
OUT2	Study conducted of crop residue (Table 23); local nutrient content factors of Kanté (2001) used.
OUT3	Calculated according to the regression models.

TABLE 23

Crop residue use for Koutiala Region

Crops	Fodder	Litter	Burying	Grazing	Burning	Other	Total removal*
	(%)						
Cotton	0	38	0	0	61	1	1
Cowpea	83	0	0	15	0	2	100
Groundnut	65	10	9	15	0	1	81
Maize	44	11	9	36	0	0	80
Millet	2	11	3	48	34	2	52
Sorghum	2	20	1	48	28	1	51

* Total removal calculated as the sum of fodder, grazing and other.

Source: Camara (1996).

TABLE 24
Estimated erosion rates for Koutiala Region

Crops	Erosion (tonnes/ha)	Explanation
Cotton	10	More than average erosion, because of burning after harvest
Cowpea	7	Average erosion
Fallow	0.5	Little erosion, because of permanent ground cover
Groundnut	10	More than average erosion, because of way of harvesting
Maize	5	Less than average erosion, as stubble is left on the fields
Millet	5	Less erosion, as stubble is left on the fields
Rice	0	No erosion, because rice is grown in the flat river valleys
Sorghum	5	Less than average erosion, as stubble is left on the fields

OUT4	Calculated according to the regression model.
OUT5	Erosion estimated for each crop according to available literature. Average erosion on cultivated land (Table 24): 7 tonnes/ha (Bah, 1992; Vlot and Traoré, 1995).

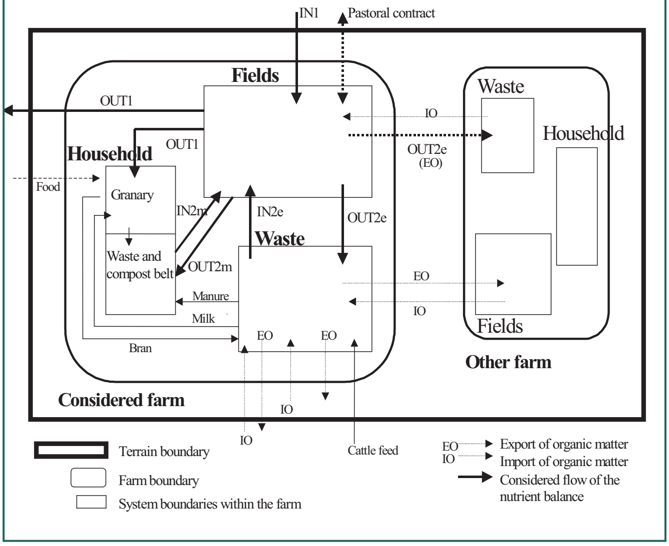
MICROLEVEL

Methods applied to determine microlevel nutrient balances differ considerably from those applied at the macrolevel and mesolevel as they are generally based on on-site inventories and monitoring studies that provide firsthand data. However, they all utilize regression models and other proxies to estimate difficult flows, such as leaching and gaseous losses. A recently developed research tool known as NUTMON (www.nutmon.org) allows co-calculation of the effects of INM and combines the calculation of nutrient flows and balances with farm economic performance under different nutrient management scenarios (Vlaming *et al.*, 2001). The methodology differentiates between 'easy to measure' and 'difficult to measure' nutrient flows. The 'easy to measure' flows, IN1, IN2, OUT1 and OUT2, can be quantified from farm survey data and expressed in monetary and labour units (Figure 1). These flows form the partial nutrient balance, as often determined in farm-level studies. The 'difficult to measure' flows, IN3, IN4, IN5, OUT3, OUT4 and OUT5, are normally estimated with transfer functions. The transfer functions are simple relations that explain 'difficult to quantify' variables as a function of easily obtainable parameters. These 'difficult to measure' nutrient flows are difficult or impossible to express in monetary terms (Van den Bosch *et al.*, 1998a). The EC-funded VARINUTS project in Kenya helped to build the above toolbox, as data was collected and nutrient flows were calculated according to the NUTMON procedures. Fifteen farms were monitored on a monthly basis for a two-year period. Further information about the NUTMON approach is available in: De Jager *et al.* (1998), Van den Bosch *et al.* (1998a) and Van den Bosch *et al.* (1998b).

One study (Kanté, 2001) compared two villages in southern Mali with similar farming systems but different land pressures as a result of higher population density and a higher ratio between cultivated land and total land. This study relied partly on CMDT farm-survey data. The nutrient-flows calculations were as per Stoorvogel and Smaling (1990), with slightly modified regression models for OUT3 and OUT4. The 'difficult flows' were estimated, while the nutrient flows of the partial balance were measured. They were quantified on the basis of a general diagram of how farmers perceive nutrient flows to occur (Figure 13). Partial balances (IN1, IN2, OUT1 and OUT2) were calculated per crop, per farm, per wealth class and per village. Finally, the complete balance with all inflows and outflows was calculated. Nutrient losses resulting from deep latrines (OUT6) were introduced at the microlevel, because the whole farm was considered part of the system.

FIGURE 13

Nutrient flows within a farm in Mali-Sud



OVERVIEW

Table 25 presents a summary of the calculation procedures and data for each scale level in this study.

CALCULATION OF SOIL NUTRIENT STOCKS

Nutrient flows and balances are not very meaningful without knowledge of nutrient stocks. This is because the rate of soil fertility decline is not simply a 'per hectare per year' unit, but also a ratio indicating the percentage change of the total nutrient supplies. Chapters 4 and 5 consider this aspect in more detail. Furthermore, nutrient stocks play a role as input data for the calculation of the nutrient flows, sedimentation, leaching and erosion, and to a lesser extent gaseous losses. The WISE database, developed by the International Soil Reference and Information Centre (ISRIC) (Batjes, 2002) was the source of all soil data for the macrolevel and part of the data for the mesolevel. The WISE database consists of a set of homogenized worldwide data of 4 382 geo-referenced soil profiles, classified according to the FAO-UNESCO original legend (1974) and the revised legend (1988). This database yielded the soil profiles for Africa: 1 799 different soil profiles, describing 81 different soil units. The FAO soil map of the world

TABLE 25

Comparison of data and procedures for calculating nutrient flows for each scale level

Flow	Macrolevel	Mesolevel	Microlevel
IN1	Fertilizer use data per crop (IFA/IFDC/FAO, 2000) and total consumption from FAOSTAT	Regional fertilizer use data and factors per crop (same as macrolevel, if no other values are available)	Local fertilizer use data per crop
IN2	Conversion of continental livestock density maps (FAO, 2000) in nutrient input by multiplying with the nutrient content, manure production and loss factor	Number of livestock (regional data) with conversion factors for nutrient input and manure management	Local livestock data, conversion factors for nutrient input (where not determined) and manure management data (or amount of manure application where available)
IN3	Related to rainfall (Leemans and Cramer, 1991) and dry deposition derived from created Harmattan dust map	Fixed value derived from macrolevel (or directly where literature available)	Fixed value derived from macrolevel (or directly where literature available)
IN4	Percentage of leguminous crop production and related to rainfall (Leemans and Cramer, 1991)	Percentage of leguminous crop production and fixed value	Percentage of leguminous crop production and fixed value
IN5	Irrigation areas receive 300 mm irrigation. Sedimentation calculated using the LAPSUS model (Schoorl *et al.*, 2002)	Estimated amount of irrigated areas and sedimentation areas	Amount of irrigation water and measured or estimated sedimentation
OUT1	Harvested areas and yields per country from FAOSTAT multiplied with nutrient content	Regional data on harvested area and yield (or production) multiplied with nutrient content	Local production data multiplied with nutrient content
OUT2	Factor nutrient content and crop residue removal factor per crop and country	Factor nutrient content and crop residue removal factor per crop	Factor nutrient content and crop residue removal factor (management)
OUT3	Regression models for N developed by De Willigen (2000) and for K in this study	Regression models for N developed by De Willigen (2000) and for K in this study	Regression models for N developed by De Willigen (2000) and for K in this study
OUT4	Regression model based on data from a study on global N emissions from agricultural land (IFA/FAO, 2001)	Regression model based on data from a study on global N emissions from agricultural land (IFA/FAO, 2001)	Regression model based on data from a study on global N emissions from agricultural land (IFA/FAO, 2001)
OUT5	Quantitative erosion-sedimentation map, computed using the LAPSUS model (Schoorl *et al.*, 2002)	Estimated values per crop, based on literature and macrolevel	Measured or estimated erosion and soil nutrient content data
OUT6	Not relevant	Not relevant	Estimated, based on number of 'consumers' and crop products used for own consumption

distinguishes 95 different soil units for Africa, apart from the classes: 'water', 'salt', 'desert', 'rock' and 'no data'. Similar soil units provided the basis for estimates of the properties for the remaining 14 soil units. Most missing soil units in the WISE database were the overall major soil groupings, e.g. Luvisols and Xerosols, because all profiles were classified at soil unit level, e.g. gleyic Luvisol or luvic Xerosol.

This study calculated the following soil properties for each soil unit: clay, pH, organic carbon, total N, exchangeable K, CEC, available P and bulk density.

Soil depth and erodibility are not parameters in the WISE database. These were estimated for each soil unit because they are necessary for the erosion-sedimentation model. The WISE database describes soil properties per horizon, but this study used only one value per soil unit. The horizon data were converted to one value per soil profile. This study considered only the upper part of the profile because this is the most important part for agriculture and because most nutrients are stored in the topsoil. The upper horizons should include at least the upper 30 cm of the profile and the lower boundary should not be deeper than 60 cm. This was done to prevent only a thin top horizon or a deep subhorizon being taken into account. These selected horizons provided the basis for calculating an average value. Annex 6 lists the resulting values.

In order to calculate the loss of P and K by erosion, it was necessary to recalculate the values to obtain values as percentages of the total soil mass. For exchangeable K, this is relatively easy, using the bulk density and the atomic mass of 39.1. For P, no direct relation exists between the total amount of P and the amount of available P, as derived from the WISE database. Different analytical methods exist to determine the amount of available P and each has a different relation with the total amount of P in the soil. According to the WISE database, 1 135 of the 1 799 profiles were analysed for available P. The Olsen method was used for 943 profiles, or 83 percent of all analyses. The Bray method was used for 6 percent and the Truong method for 3 percent of all analyses. According to Landon (1991), the values of P-Olsen correspond with total P as follows: > 15 is high, 5–15 is medium and < 5 is low for P-Olsen, whereas for total P, > 1 000 mg/kg is high, 200–1 000 mg/kg is medium and < 200 mg/kg is low. This rough classification is currently the best available. A regression equation based on the Olsen method was developed to relate available P to total P. It was modified slightly for the influence of the Bray and Truong methods:

$$P_{total} = 13 \times P_{available}^{1.5}$$

Chapter 4
Results

MACROLEVEL

Ghana

Figure 14 shows the simulated land use map of Ghana. Cocoa and oil-palm are the dominant crops in the wetter southwest of the country, and maize, millet, sorghum and groundnuts in the drier north. Cassava is found between these zones and in the southeast. Based on this land use map, Table 26 presents the total and per-crop nutrient balances for Ghana. The differences between the crops are large, e.g. coconut and cassava are very depleting, whereas fallow and groundnuts have an almost neutral nutrient balance.

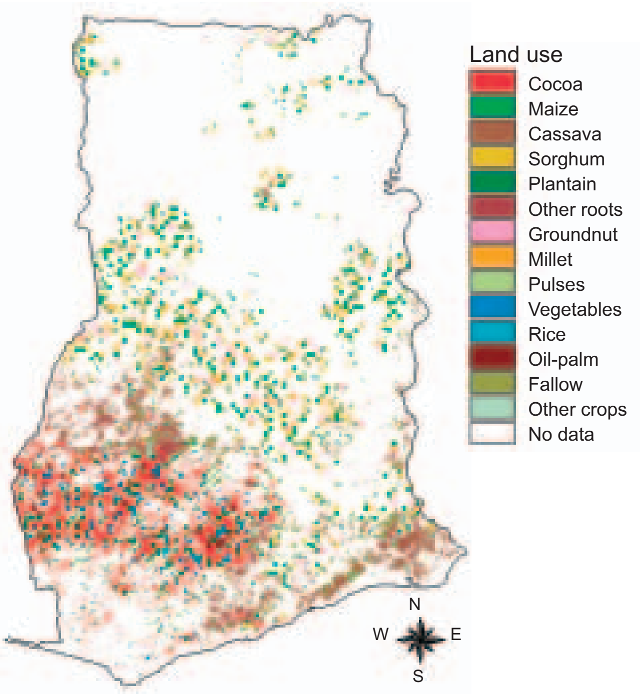


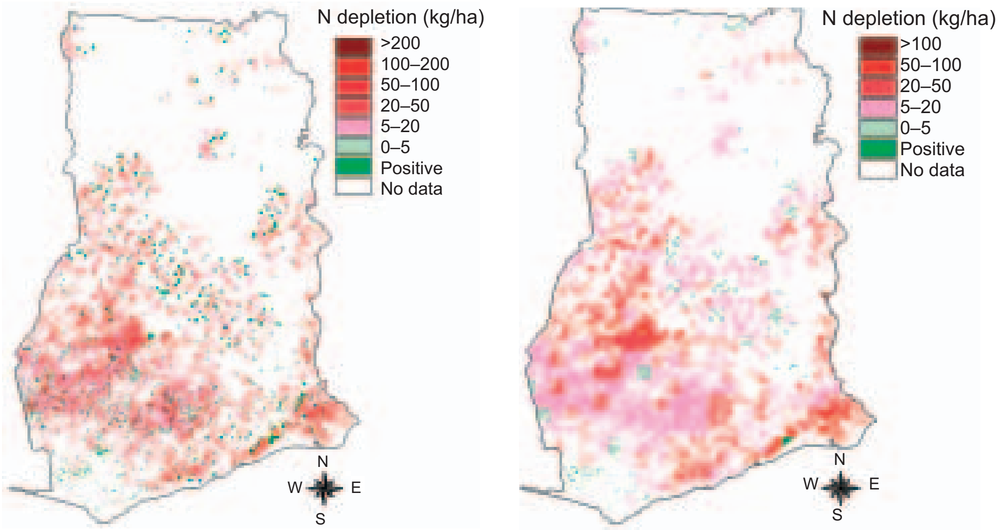
FIGURE 14
Simulated land use map of Ghana

The left-hand map in Figure 15 shows the N balance at the original 1-km resolution. Fallow and groundnuts have almost neutral nutrient balances, whereas coconut and cassava have strongly negative balances (Table 26). The pattern of this map is very scattered and the uncertainty of the results is very high because of the uncertainties in the land use map. Therefore, the map was aggregated to a 20-km grid (using the median value) in order to obtain a picture of the total farming system, instead of individual crops (right-hand map in Figure 15). The highest depletion rates are in the southeast and the central-west parts of Ghana, which corresponds to the cassava area.

TABLE 26
Nutrient balance per crop and total balance, Ghana

Crops	Area	N	P	K
	(ha)		(kg/ha)	
Banana	4 733	-41.2	-3.1	-11.6
Cassava	619 760	-67.7	-9.0	-57.4
Citrus	41 867	-14.0	-1.5	-23.3
Cocoa	1 246 500	-15.8	-2.5	-12.9
Coconut	53 100	-368.3	-44.9	-77.6
Coffee	19 800	-10.0	-1.0	-15.8
Cotton	50 387	-24.0	-10.2	-26.6
Fallow	828 555	-9.0	0.6	-1.3
Groundnut	185 077	-1.7	-5.1	-12.7
Maize	681 707	-21.2	-4.8	-15.2
Millet	178 910	-21.6	-5.2	-21.7
Oil-palm	106 667	-33.7	-6.4	-46.3
Other fruits	17 133	-27.0	-2.9	-36.2
Other roots	213 787	-32.1	-1.7	-33.1
Plantain	241 233	-10.6	-0.5	-37.7
Pulses	153 333	-16.9	0.1	-5.4
Rice	117 800	-35.3	-5.8	-19.0
Rubber	15 710	2.5	0.3	-11.8
Sorghum	322 553	-17.4	-6.0	-13.2
Sugar cane	5 600	-2.6	-2.2	-31.1
Sweet potatoes	60 200	-5.7	-0.5	-11.9
Tobacco	3 900	-28.3	-4.2	-38.9
Vegetables	131 688	-51.0	-7.0	-34.8
Overall	5 300 000	-27.0	-4.0	-21.0

FIGURE 15
Nitrogen balance for Ghana, per 1-km grid cell (left) and per aggregated grid cell of 20 km (right)

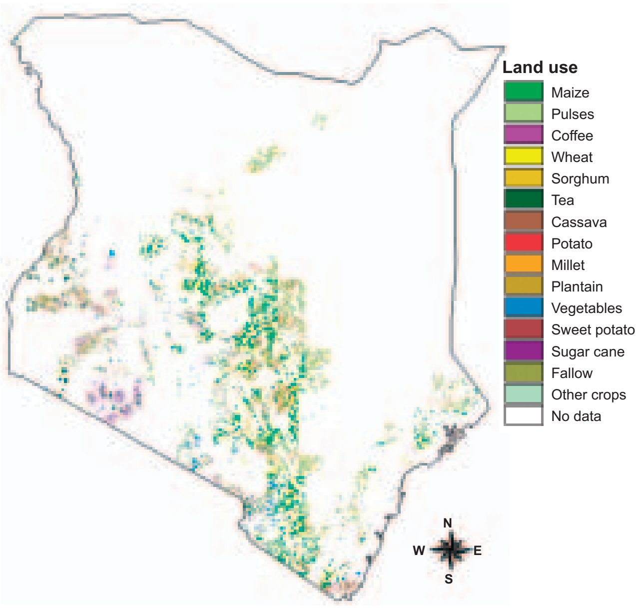


Kenya

The simulated land use map of Kenya (Figure 16) shows an intricate pattern of land use. Agriculture is concentrated in the central and west highlands. Tea and coffee is found mainly in the west of the country and maize mainly in the central-east part. Table 27 presents the nutrient balances calculated on the basis of Figure 16. Figure 17 shows the N balance in a spatially explicit way. Positive values in the central-east part are mainly due to pulses and fallow. There is considerable depletion around Mount Kenya and in west Kenya.

FIGURE 16

Simulated land use map of Kenya



Mali

The simulated land use map for Mali (Figure 18) shows a scattered pattern with millet and maize mainly in the drier northern zone. Rice is found mainly in

FIGURE 17

Nitrogen balance for Kenya, per 1-km grid cell (left) and per aggregated grid cell of 20-km (right)

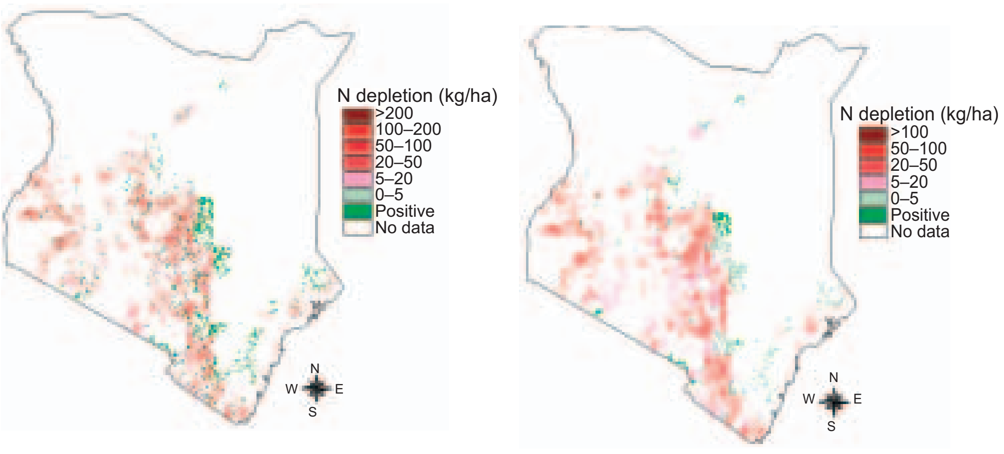


TABLE 27

Nutrient balance per crop and total balance, Kenya

Crops	Area	N	P	K
	(ha)		(kg/ha)	
Bananas	40 333	-25.0	7.8	-35.9
Barley	22 267	-26.9	31.6	-26.7
Cassava	98 333	-101.6	-7.3	-45.6
Citrus	6 521	-7.6	7.8	-17.2
Coconuts	15 000	-443.3	-42.0	-75.2
Coffee	178 136	-22.2	7.3	6.7
Cotton	38 866	-66.3	19.6	-23.1
Fallow	915 802	-28.5	-1.5	-2.4
Groundnuts	15 145	-5.5	-1.6	-22.1
Maize	1 523 587	-48.5	-5.0	-35.2
Millet	88 233	-17.1	-4.0	-21.6
Other fruits	23 482	1.1	53.6	113.7
Other roots	2 000	-21.8	-1.2	-17.8
Plantains	85 333	-70.1	0.8	-26.6
Potatoes	94 051	-32.5	10.7	-45.7
Pulses	700 000	-11.5	3.2	-6.4
Rice	14 607	-47.5	3.7	-60.4
Sesame seed	28 000	-5.9	-2.9	-4.8
Sorghum	136 667	-12.8	-3.3	-22.1
Sugar cane	58 000	-34.7	-10.5	-103.5
Sunflower seed	9 432	-45.9	-4.9	-18.4
Sweet potatoes	71 333	-63.6	-10.4	-78.5
Tea	114 964	-97.9	-6.6	-40.1
Tobacco	13 980	-49.8	15.8	-75.4
Vegetables	81 523	-51.7	34.3	-53.0
Wheat	144 405	-31.0	25.4	-38.3
Overall	4 520 000	-38	0	-23

TABLE 28

Nutrient balance per crop and total balance, Mali

Crops	Area	N	P	K
	(ha)		(kg/ha)	
Cassava	907	-44.7	-6.5	-50.1
Cotton	496 401	-10.7	-6.5	-21.4
Fallow	1 402 427	-0.5	0.7	0.9
Fibres	2 000	-4.9	0.2	-3.0
Groundnuts	190 248	-7.9	-1.6	-7.2
Maize	286 232	-29.6	-3.6	-21.2
Millet	920 416	-22.5	-5.9	-27.3
Other fruits	3 197	-14.5	-2.5	-64.0
Pulses	319 715	-8.6	0.6	-6.9
Rice	328 494	-5.5	-5.6	-30.6
Sorghum	634 920	-18.9	-6.8	-17.8
Sugar cane	4 477	-23.9	-17.9	-89.0
Sweet potatoes	3 730	-33.9	-7.4	-56.9
Tobacco	376	-47.6	-7.4	-71.6
Vegetables	48 564	-57.3	-11.0	-54.6
Wheat	3 104	-36.7	-8.4	-28.2
Overall	4 650 000	-12.0	-3.0	-15.0

the irrigated areas along the Niger River. Table 28 presents the nutrient balances for Mali based on this land use map. Food crops, such as millet, sorghum and maize, have more negative nutrient balances. The cash crops and legumes are less depleting.

FIGURE 18
Simulated land use map of Mali

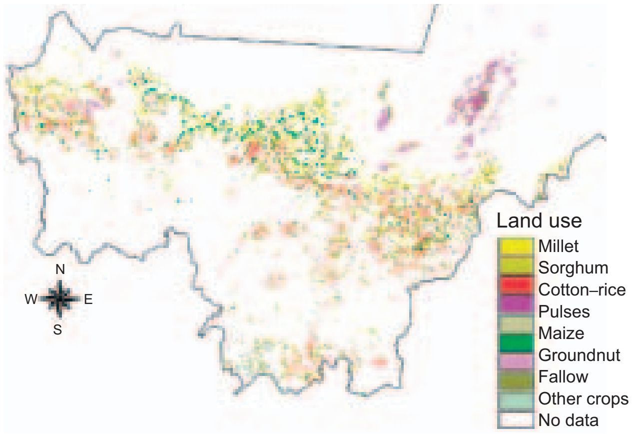
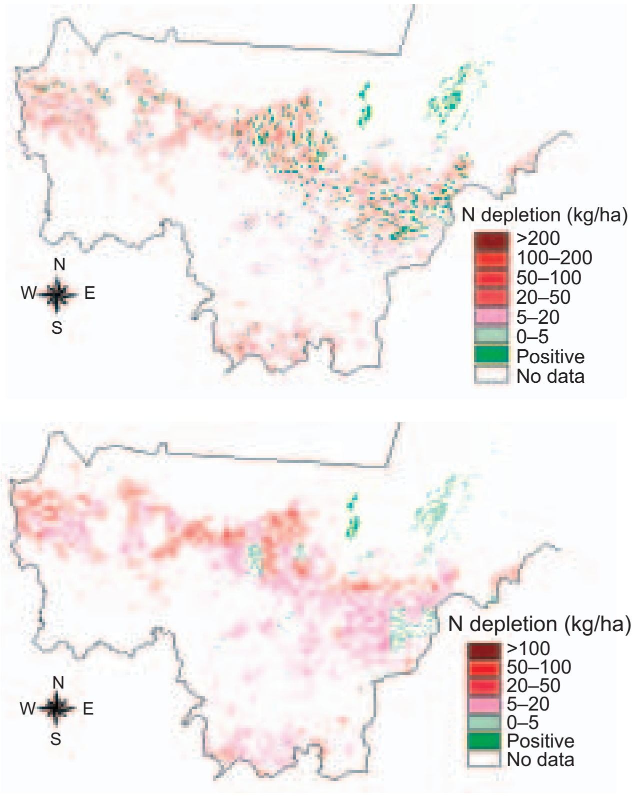


FIGURE 19
Nitrogen balance for Mali, per 1-km grid cell (above) and per aggregated grid cell of 20-km (below)



The N-balance map of Mali (Figure 19) is mainly positive in the central part of Mali (rice and fallow), while the northern border of the agricultural zone has, on average, greater depletion (millet and maize).

Figure 20 shows all N flows per country. In Kenya, the input of mineral and organic fertilizer is relatively important, whereas Ghana has a larger input by atmospheric deposition because of Harmattan dust. Outflows by leaching and gaseous losses are somewhat greater in Kenya because more mineral fertilizers are used. Most striking is the importance of erosion in Kenya, which is caused by the topography and the relatively fertile volcanic soils. Annex 8 details the N, P and K flows per crop.

MESOLEVEL

Cocoa-based farming system in Ghana

Figure 21 presents the nutrient balances for the two selected districts. The balance for Nkawie District

FIGURE 20
Overall nitrogen flows for Ghana, Kenya and Mali

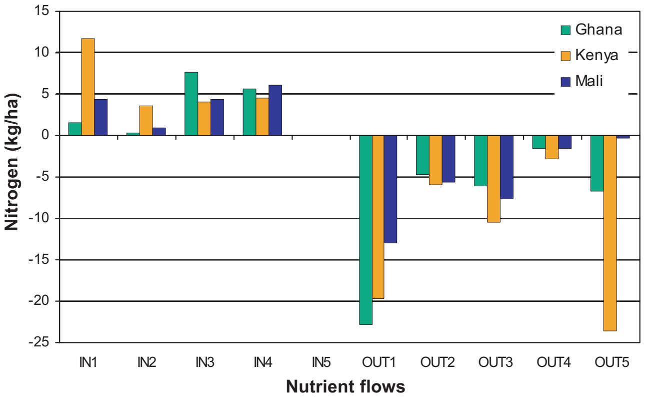


FIGURE 21
Total nutrient balance for Nkawie and Wassa Amenfi districts

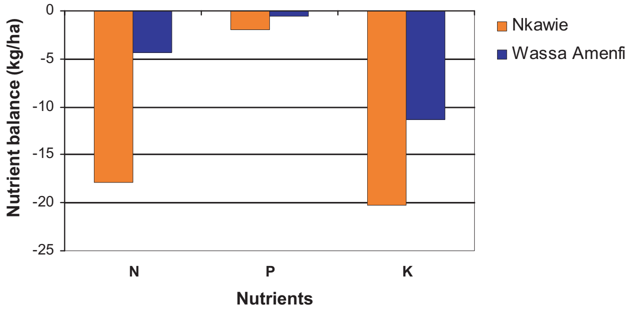
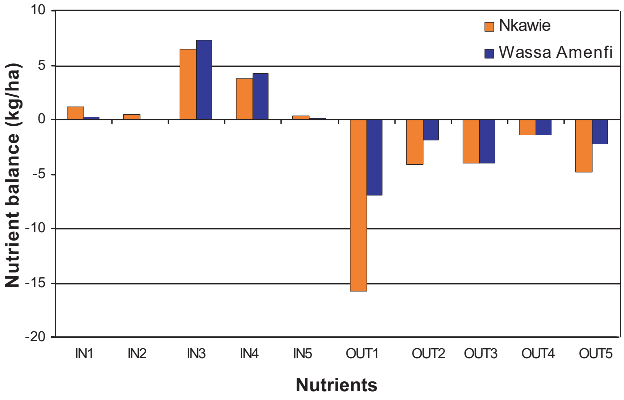


FIGURE 22
Nitrogen flows for both districts, Ghana



is considerably more negative than that for Wassa Amenfi District. The main reason for this difference is the area under cocoa, which is 58 percent of the total area in Nkawie District, and 90 percent in Wassa Amenfi District. The nutrient balance for cocoa is only slightly negative as opposed to most other crops. These other crops cause the total nutrient balance for Nkawie District to be more negative. Cassava, yam and cocoyam have strongly negative nutrient balances (Tables 29 and 30). These root crops receive little mineral or organic fertilizer, while crop products remove many nutrients.

Figure 22 presents the individual nutrient flows for the two districts. Nutrient losses by crop products (OUT1) cause the largest negative values. The other outflows are more or less of equal importance. The most striking aspect is the very low input of fertilizer. The farming system depends almost completely on natural resources, which are inputs by deposition (IN3) and N fixation by trees and non-symbiotic N fixation (IN4). This results in a total N input of 12 kg/ha. Annex 10 presents the nutrient balances for each crop.

TABLE 29
Nutrient balance for Nkawie District

Crop	Area	N	P	K
	(ha)		(kg/ha)	
Cassava	11 838	-68.3	-9.6	-59.0
Cocoa	48 493	-3.2	-0.1	-8.5
Cocoyam	9 514	-50.8	-3.3	-39.9
Fallow	14 600	-0.6	0.9	-2.5
Maize	11 455	-32.4	-6.3	-20.3
Plantain	11 725	-8.7	-0.3	-35.6
Rice	1 462	7.5	4.0	-9.8
Yam	1 175	-55.0	-3.7	-42.9
All crops	110 262	-18.0	-1.9	-20.3

TABLE 30
Nutrient balance for Wassa Amenfi District

Crop	Area	N	P	K
	(ha)		(kg/ha)	
Cassava	7 700	-53.3	-7.6	-50.3
Cocoa	240 961	-1.5	-0.2	-9.2
Cocoyam	3 000	-34.0	-1.9	-26.1
Fallow	7 300	1.8	0.9	-3.2
Maize	5 650	-23.8	-5.4	-13.5
Oil-palm	900	-29.2	-7.2	-54.1
Plantain	5 000	-6.2	-0.5	-35.4
Rice	2 112	10.1	5.0	-7.3
Vegetables	250	-57.8	-7.0	-29.3
Yam	1 500	-85.8	-6.0	-63.3
All crops	274 373	-4.3	-0.5	-11.4

Tea–coffee–dairy–based farming system in Kenya

The nutrient balance for the tea–coffee–dairy zone of Embu District is very negative. All crops except tea and coffee have strongly negative nutrient balances (Table 31). Nutrients in crop products, leaching and, in particular, erosion are the major contributors to this negative balance (Figure 23). Although the quantity of eroded soil is not very large, nutrient losses are large because the soil is nutrient rich (being developed on young volcanic deposits). As a consequence, they are rather fertile with high organic-matter contents.

Figure 24 shows the N flows for three important crops in the coffee-tea-dairy zone of Embu District. All inflows are very small compared with the outflows. The differences between the coffee (a cash crop) and maize and beans (food crops) are evident. Larger amounts of mineral fertilizer (IN1) are used for coffee than for the food crops. In this connection, fertilizer use on cash crops may cease if world market prices are too low, as is now the case for coffee.

Nutrient losses due to leaching and erosion are small for the perennial coffee crop. Beans obtain part of their N requirements through symbiotic N

TABLE 31
Nutrient balance of the tea-coffee-dairy zone, Embu District

Crop	Area (ha)	N	P	K
			(kg/ha)	
Arrow roots	260	-52.0	-6.8	-47.0
Beans	2 748	-142.0	-25.9	-23.8
Cassava	515	-285.1	-52.1	-96.3
Coffee	8 813	-39.1	-7.6	-7.3
Cowpeas	280	-107.7	7.5	-26.6
Fallow	1 800	-24.6	-0.9	-1.1
Maize	5 143	-174.2	-31.2	-73.0
Napier	602	-169.5	-22.6	-179.2
Potatoes	678	-144.9	33.3	-45.3
Sorghum	207	-104.5	-34.2	-30.8
Sweet potatoes	140	-177.8	-32.3	-91.9
Tea	1 092	-16.3	-1.4	-2.3
All crops	20 678	-95.6	-14.9	-33.1

FIGURE 23
Nitrogen flows for the tea–coffee–dairy zone, Embu District

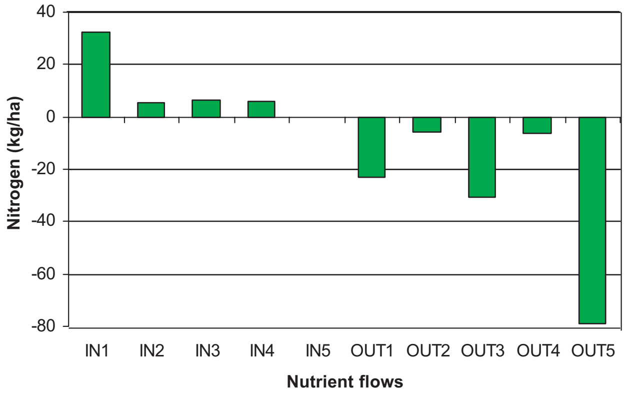
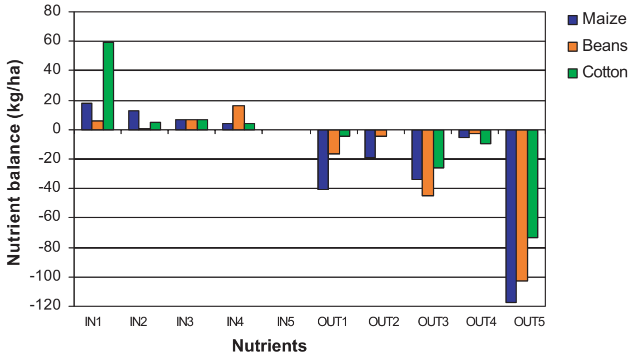


FIGURE 24
Nitrogen flows for three major crops, Embu District



fixation (IN4). However, this quantity is quite small compared with the losses. Erosion (OUT5) is the most important outflow, mainly because of the large nutrient content of the soil. Annex 10 presents the nutrient balances for each crop.

Cotton-based farming system in Mali

The overall nutrient balance for the cotton-based farming system in Koutiala Region is moderately negative (Table 32). For P, the nutrient balance is positive. The nutrient balance for cotton compensates in part for the other crops, because cotton receives a large amount of mineral fertilizer and manure. The most important losses are through crop products (OUT1) and leaching (OUT3) (Figure 25). Losses

TABLE 32
Nutrient balance for Koutiala Region

Crop	Area (ha)	N	P	K
		(kg/ha)		
Cotton	144 713	-13.8	12.4	17.4
Cowpea	5 637	-11.5	-2.8	-5.4
Fallow	227 200	-2.9	0.6	0.1
Groundnut	13 411	-7.0	-3.0	-10.5
Maize	57 020	-25.9	-0.9	-19.1
Millet	101 294	-20.4	-5.7	-23.8
Rice	5 569	-4.4	0.8	-18.0
Sorghum	130 254	-15.6	-2.1	-25.2
All crops	685 098	-12.3	1.4	-6.6

by erosion are relatively small because the soil is very poor in nutrients.

Cotton as a cash crop and millet and sorghum as food crops are the main crops in Koutiala Region. The differences between these crops are evident. Sorghum and millet receive little fertilizer, while losses due to crop products and crop residue removal are similar to cotton (Figure 26). However, millet and sorghum do receive fertilizer indirectly as the fertilizer applied to cotton has an effect on millet and sorghum in the next crop cycle. Annex 10 presents the resulting nutrient balances for each crop.

MICROLEVEL

Farms in Embu District, Kenya

The VARINUTS project monitored 15 farms, 3 farms per AEZ (Table 3), for two years using the NUTMON approach. The nutrient

FIGURE 25
Nitrogen flows of the cotton-based system, Koutiala Region

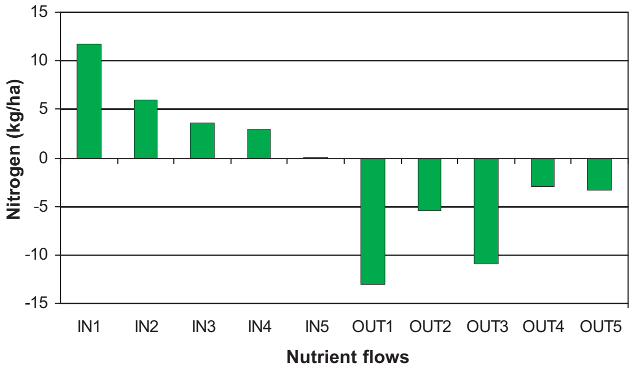


FIGURE 26
Nitrogen flows for the three major crops, Koutiala Region

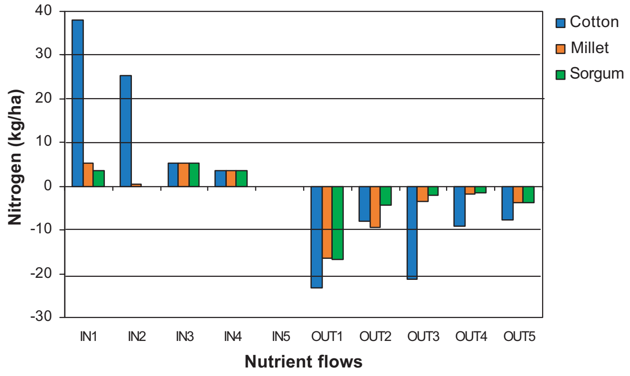


TABLE 33
Nutrient balance per AEZ

AEZ	N	P	K
1	-143	-4.0	-11.7
2	-197	-11.6	-30.3
3	-143	-3.6	-31.2
4	-30	8.8	1.8
5	-27	-1.9	6.6

Source: SC-DLO *et al.*, 2000.

FIGURE 27
Farm-level nitrogen flows per AEZ

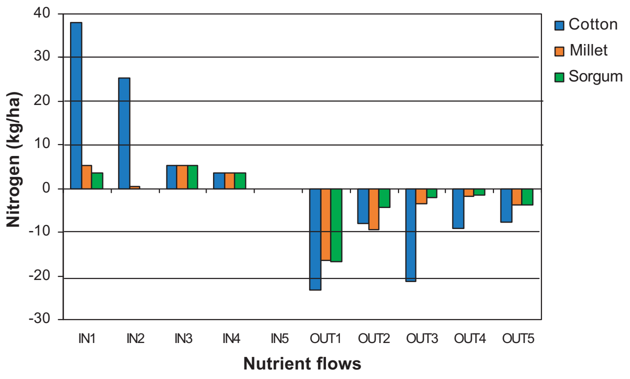
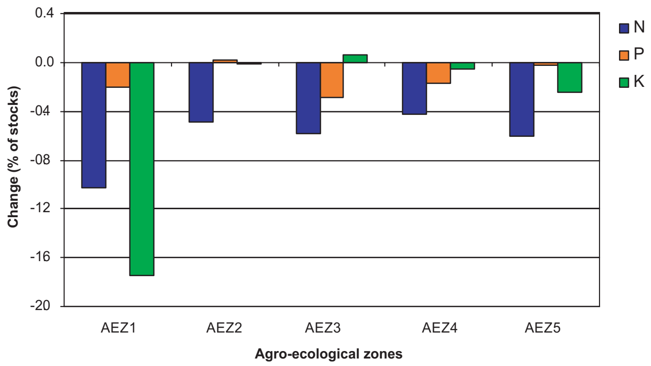


FIGURE 28
Nutrient balance in relation to the soil nutrient stocks



balances show clear gradients with the AEZs (Table 33). Although these results are per AEZ, which is mesolevel, the study is based on averages from three farms per AEZ. This means that no mesolevel data were involved, which makes it a microlevel study. The farms at the higher altitudes rely more on external inputs and have larger losses owing to leaching, gaseous losses and erosion (Figure 27). Although AEZ1, AEZ2 and AEZ3 appear to have a comparable total balance, the results are significantly different when nutrient losses are compared with the nutrient stocks. Figure 28 shows that AEZ1 has the greatest relative nutrient losses.

The variations between farms in each AEZ and between AEZs were very large for each soil property (Table 34). The average coefficients of variance (CVs) and the number of soil units identified can serve as indicators of on-farm variation. The average number of soil units identified per farm decreased from five in the upper parts of the district to three in AEZ5 (Table 35). The variation between the units is significant and especially large in the zones where few units were identified.

CVs were also calculated for each individual soil unit with more than two samples. Again, especially in AEZ5, high CVs were found. A possible reason is

TABLE 34

Soil properties for all farms and AEZs

AEZ	Farm	Area (ha)	pH	C_{tot} (g/kg)	N_{tot} (g/kg)	P_{tot} (mg/kg)	P_{olsen} (mg/kg)	K (cmol/kg)
1	1	1.2	4.1	39.4	9.2	1 998	4.85	5.4
	2	1.1	4.3	28.2	7.2	2 429	2.42	2.9
	3	1.7	4.9	29.9	6.2	2 207	3.18	5.3
2	4	1.5	4.6	24.8	5.5	2 030	4.48	9.1
	5	1.1	4.2	23.1	7.1	2 256	1.32	5.8
	6	2.3	4.6	26.5	6.5	1 998	2.84	19.3
3	7	1.3	4.3	22.8	3.8	2 122	3.18	19.3
	8	1.7	4.4	25.6	4.8	1 876	1.85	3.9
	9	3.8	4.9	20.4	4.6	1 696	1.95	8.2
4	10	2.4	5.5	17.8	2.2	1 035	1.94	16.8
	11	2.4	6.0	15.7	1.9	568	6.16	8.7
5	13	4.1	6.4	7.7	0.7	510	6.25	5.2
	14	3.7	4.5	5.5	0.9	3 990	11.28	3.0
	15	1.4	5.2	6.4	1.1	2 669	16.14	6.2

Source: Stoorvogel *et al.* (2000).

TABLE 35

Average coefficients of variance for soil properties

AEZ	No. of units	CV for properties between units (%)					CV for properties within units (%)				
		pH	N_{tot}	P_{tot}	C_{tot}	K	pH	N_{tot}	P_{tot}	C_{tot}	K
1	4.3	11	20	11	11	55	8	25	9	13	56
2	5.3	11	13	7	19	65	9	10	8	16	92
3	4.7	14	31	13	17	80	6	8	9	15	61
4	3.3	4	10	20	15	25	4	9	12	13	56
5	3.0	52	46	101	49	83	2	22	12	17	79

Source: Smaling *et al.* (2002).

that the identification of soil units is more difficult because of the flat topography.

Figure 29 shows that farm nutrient balances are also variable. In part, these differences reflect soil properties, e.g. leaching is less in soils with a high organic-matter content, and in part, differences in management, such as crop choice, fertilizer application, and soil conservation measures.

FIGURE 29

Farm nutrient balance for nitrogen per AEZ

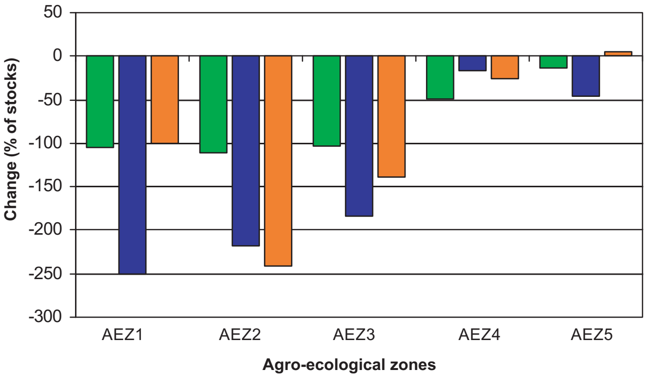


TABLE 36

Characteristics of M'Peresso and Noyaradougou

Characteristics	M'Peresso	Noyaradougou
Altitude (m)	297	0531
Climate zone	Semi-arid	Subhumid
CMDT region	Koutiala	Sikasso
Dominant ethnology	Minianka	Senoufo
Number of inhabitants	977	557
Number of emigrants	114	453
Number of farms	64	29
Livestock density (TLU/ha)*	0.36	0.12

* TLU = tropical livestock unit (standard bovine 250 kg).
Source: Kanté (2001).

Villages in Mali-Sud, Mali

The villages of M'Peresso and Noyaradougou in Mali were examined for the microlevel analysis. Both villages are within the CMDT region of Mali-Sud. At first glance, they have comparable farming systems (Kanté, 2001). Cotton is the basic cash crop and cereals, such as maize, sorghum and millet, the major food crops. Livestock is important. A closer examination shows that land pressure is considerably higher in M'Peresso (higher population density, higher ratio of cultivated land to total land) and, as a consequence, the management of crop residues is more intensive in M'Peresso. Similarly, one might say that Noyaradougou has a labour shortage such as to prevent the village from recycling all crop residues. The burning of residues is 3 percent in M'Peresso compared with 16 percent in Noyaradougou. In addition, cotton yield increments as a result of manure application are larger in M'Peresso. Noyaradougou uses more mineral fertilizers to compensate.

Tables 36–38 show some general characteristics of the two villages. The total N stocks (0–40 cm) range from 600 kg/ha in M'Peresso to 900 kg/ha in Noyaradougou. The total P stocks (0–40 cm) range from 400 kg/ha in M'Peresso to 600 kg/ha in Noyaradougou. These differences are expressed terms of the soil fertility management (Table 39) and the nutrient balances (Table 40).

TABLE 37

Average cultivated areas per farm, two villages, Mali

Village	Fallow	Cotton	Maize	Sorghum	Millet	Groundnut
			(ha)			
M'Peresso	5.8	4.3	0.9	3.2	2.6	1.0
Noyaradougou	5.4	4.4	2.9	1.0	0.7	0.3

Source: Kanté (2001).

TABLE 38

Average quantity of mineral fertilizer, two villages, Mali

Villages	Crops	Cotton complex*		Cereal complex*		Urea	
		kg/ha	Fields**	kg/ha	Fields**	kg/ha	Fields**
M'Peresso	Cotton	123	58	-	-	53	58
	Maize	91	19	98	25	84	39
	Sorghum	72	6	-	-	36	6
Noyaradougou	Cotton	149	70	130	5	73	70
	Maize	135	9	100	68	89	68
	Sorghum	-	-	98	8	52	11
	Millet	142	6	85	26	64	29
	Cowpea	-	-	159	10	183	12

* Cotton complex NPK = 14:9.6:10 and cereal complex NPK = 15:6.5:12.5.
** Number of fertilized fields.
Source: Kanté (2001).

Farm household members were used as the basis for assigning households by three nutrient management groups (Class 1 = good, Class 3 = poor). Interviews focused on three groups for this purpose: older men, younger men, and women. The class assigned largely reflected: the number of household members; possession of animals and, hence, manure; and carts. Class 3 compensates for the lack of manure by applying more mineral fertilizer per hectare (but has fewer hectares). A further partitioning of the above generates the outputs per village per class (Table 41). An annual evaluation of the classification can result in farmers being promoted or relegated to another class.

TABLE 39

Observed differences between two villages, Mali

	M'Peresso	Noyaradougou
Fallow/cultivated land ratio	0.6	1.4
Total N in soil (g/kg)	0.20	0.31
Total P in soil (mg/kg)	126	171
Available organic manure (tonnes)	26	11
Mineral fertilizer use on cotton (kg/ha)	102	155
Crop residues as animal feed (%)	35	15
Crop residues as compost (%)	16	43
Crop residue burning (%)	3	16
Partial N balance for cotton (kg/ha)	58	22
Partial N balance for maize (kg/ha)	-30	2

Source: Kanté (2001)

TABLE 40

Partial nutrient balances for two villages, Mali

	M'Peresso			Noyaradougou		
	N	P	K	N	P	K
IN1	15.3	4.0	4.3	41.9	8.3	10.4
IN2	16.8	3.3	22.7	10.8	2.0	14.6
OUT1	18.7	2.2	4.7	25.2	3.3	6.3
OUT2	14.1	1.2	36.7	16.7	1.1	21.1
Partial balance	-0.7	4.0	-14.4	10.7	6.0	-2.4

Source: Kanté (2001).

TABLE 41

Partial nitrogen balance for different classes and villages, Mali

	M'Peresso			Noyaradougou		
	Class 1	Class 2	Class 3	Class 1	Class 2	Class 3
Number of farms	3	10	7	8	5	7
IN1	15.9	16.4	13.4	42.9	42.1	40.6
IN2	23.8	16.4	14.5	11.5	8.1	11.8
OUT1	21.6	18.8	17.3	28.2	24.0	22.6
OUT2	19.4	13.3	13.1	17.3	15.0	17.3
Partial balance	-1.3	0.7	-2.5	8.9	11.2	12.5

Source: Kanté (2001).

Chapter 5

Discussion

A COMPARISON OF MACROLEVEL METHODOLOGIES: 1990 AND 2003

The macrolevel results show that Kenya has the greatest nutrient depletion for N and K, followed by Ghana and Mali (Table 42). For P, Ghana and Mali show slightly negative balances, while the P balance for Kenya is neutral. One reason may be that farmers in Kenya applied 30 000 tonnes P with mineral fertilizer (IN1), which is 15 times that applied in Ghana and 5 times that applied in Mali. However, P depletion may also be underestimated in the erosion flow, as total P is derived from available P. In the volcanic soils of Kenya, there can be little available P when total P is large as most P is bound strongly to P-fixing soil particles. Table 42 also shows that results of the continental study by Stoorvogel and Smaling (1990) are reasonably in line with those of the present study, particularly for Ghana and Mali. Nutrient depletion in Kenya is less severe in the present study than that predicted by Stoorvogel and Smaling for 2000.

The macrolevel calculation procedure presented in Chapter 3 underwent a number of important methodological improvements compared with the original continental study by Stoorvogel and Smaling. First, the methodology was spatially explicit. This made it possible to take the spatial variation of soils and climate into account. It also provided the possibility to indicate areas with varying degress of nutrient depletion within the country. The procedures to calculate the nutrient flows also underwent significant improvement (Table 43). Finally, the soil nutrient stocks were quantified for each soil unit instead of only three soil fertility classes.

COMPARING MACRO–MESO AND MICRO–MESO LEVELS

This study introduced the mesolevel in order to add value to the approaches that exist at national and farm level. The hypothesis was that the mesolevel could offer a suitable entry point for policy-makers and private-sector intervention, where

TABLE 42
Nutrient depletion, comparison between present study (2003) and Stoorvogel and Smaling (1990)

	Macrolevel			Stoorvogel and Smaling, 1983*			Stoorvogel and Smaling, 2000*		
	N	P	K	N	P	K	N	P	K
Ghana	-27	-4	-21	-30	-3	-17	-35	-4	-20
Kenya	-38	0	-23	-42	-4	-29	-46	-1	-36
Mali	-12	-3	-15	-8	-1	-7	-11	-2	-10

* Stoorvogel and Smaling (1990).

TABLE 43
Improvements in calculation procedure compared with the 1990 study

Flow	Methodological improvements
IN1	Fertilizer use data per crop (IFA/IFDC/FAO, 1999) available
IN2	Livestock density maps and differentiation between cattle, small ruminants and poultry included
IN3	Harmattan deposition map and more literature values available
IN4	N fixation percentages based on much more literature
IN5	Feedback between erosion-sedimentation from LAPSUS model introduced
OUT1	Comparable with the 1990 study
OUT2	Comparable with the 1990 study
OUT3	New leaching models, based on much more data, especially for N (De Willigen, 2000)
OUT4	New regression model, based on much more data from IFA/FAO (2001)
OUT5	Erosion simulated with a dynamic landscape model LAPSUS (Schoorl *et al.*, 2002)

macrolevel and microlevel are not appropriate for policy-making at subnational level. Within such a mesolevel system, the commercial component functions as the engine of the farming system and allows for intensification and expansion. This cash component can function as a driver for soil fertility management.

This study has shown that it is possible to construct a proper mesolevel nutrient balance provided sufficient data is available. The mesolevel results provide information that cannot be deduced from macrolevel and microlevel studies. For example, in Mali, the national nutrient balance per crop provides no intervention points for the CMDT and the cotton farmers as the scale is too coarse for targeted policies and institutional facilitation. At the microlevel, the village studies show relevant differences as to nutrient management, based on population density. For the CMDT, it is important to know about such differences and their causes. However, at the same time, its business-like structure forces it to act on the basis of subnational production targets and averages.

The above also holds for the Kenyan AEZ2, where differences in nutrient balances between farms were large (Figure 29). For this case, differences between AEZs are, in spite of farm-to-farm variation, more meaningful as entry-points for policy-makers and other stakeholders working at the district level. For intervention, it is also important to know that the relative depletion is much greater in AEZ1 than in the other zones (Figure 28). In Ghana, the macrolevel nutrient balance shows values for the different crops in different grid cells, and shows that cocoa is not causing greater nutrient depletion than other crops. However, what it does not show is the development of cocoa production in the two districts, and how this affects the soil fertility level. For this, and for actions to be proposed, mesolevel nutrient balances are needed. The figure for the total balance in this case is less important than differences between crops and individual flows that have a price (IN1 and IN2, OUT1 and OUT2).

Table 44 compares the mesolevel nutrient balances with the macrolevel balances of the study areas. It was not possible to make this comparison for the tea-coffee-dairy zone of Embu District because this study area was too small to determine

TABLE 44

Comparison of the nutrient balance between macrolevel and mesolevel

	Macrolevel			Mesolevel		
	N	P	K	N	P	K
Nkawie, Ghana	-42	-5	-23	-18	-2	-20
Wassa Amenfi, Ghana	-15	-2	-19	-4	-1	-11
Koutiala, Mali	-8	-3	-12	-12	1	-7

a realistic nutrient balance at the macrolevel, i.e. the resolution at the macrolevel is too low. The table shows that the 'macro' figures for Ghana are considerably more negative than the 'meso' figures. This is because at the macrolevel the area under cocoa in the study areas is underestimated and too large an area is assigned to crops that have more negative nutrient balances. The mesolevel corrects this 'error', which stems from the macrolevel land-use map approach (Chapter 3). The macrolevel results for Mali agree reasonably well with those at the mesolevel, because of the similarity in land use at both levels (Table 45).

TABLE 45

Comparison of harvested areas for Koutiala Region

	Macrolevel	Mesolevel
	%	
Cotton	21	21
Cowpea	5	1
Fallow	38	33
Groundnut	5	2
Maize	1	8
Millet	11	15
Rice	0	1
Sorghum	18	19

Unlike the macrolevel, the mesolevel analysis can also take specific management decisions and physiographic differences into account. This is the added value compared with the macrolevel approach. This also explains the differences between the results at the macrolevel and the mesolevel. For example, at the mesolevel in Ghana the small amount of erosion for land under cocoa was included in the OUT5 model, whereas erosion at the macrolevel is not land-use specific, adding to the overestimation of erosion and, hence, nutrient depletion for cocoa.

Microlevel studies provide a picture of the variation within a mesolevel unit. It is possible to include relevant management factors, and monitoring can check whether changes in nutrient management have a bearing on the nutrient balance and farm income. At the mesolevel, interventions can be targeted on the basis of microlevel variation by categorizing individual farms and villages into, for example, 'good', 'moderate', and 'poor' nutrient managers. Figure 29 illustrates the differences between farms in Embu District. Interventions can then be tailored to the diversity and dynamics in nutrient management as observed in the area. The villages studied in Mali provide evidence of the importance of population density and available land area as drivers of cotton production and farm nutrient management. M'Peresso, with a higher land pressure, has more livestock, uses more crop residues and less mineral fertilizer, and has a lower soil fertility. Noyaradougou, with a lower land pressure, has fewer livestock, uses fewer crop residues and more mineral fertilizer, which results in a more positive nutrient balance. For the CMDT, at the mesolevel, this could lead to a dual business approach, i.e. for areas under pressure and those under less pressure.

TABLE 46
Mesolevel nutrient balances

Study area and crop	N	P	K
		(kg/ha)	
Ghana, Nkawie District	-18	-2	-20
Cocoa	-3	0	-9
Ghana, Wassa Amenfi District	-4	-1	-11
Cocoa	-2	0	-9
Kenya, Embu District	-96	-15	-33
Coffee	-39	-8	-7
Tea	-16	-1	-2
Mali, Koutiala Region	-12	1	-7
Cotton	-14	12	17

COMPARING THE MESOLEVEL BETWEEN COUNTRIES

The nutrient balance at the mesolevel shows large differences between the three countries (Table 46). These differences stem from different physiographic circumstances and management. The cocoa-based farming system in Ghana receives very few inputs, which results in low yields and low but steady soil nutrient depletion. On the other hand, the cotton-based system in Mali is a relatively high-input system with little nutrient depletion, or even a positive balance in the case of P.

In all three farming systems, the cash crops are less nutrient depleting, or even have a positive nutrient balance, whereas the food crops have more negative nutrient balances. The reasons for the smaller depletion vary. Cocoa in Ghana receives very few inputs, but also has small outputs as a result of low crop production. In addition, cocoa is a shaded perennial crop, so leaching and erosion are minimal. Coffee and tea in Kenya receive more fertilizers than do food crops, but leaching and erosion remain important outflows. Cotton in Mali functions as the engine of the farming system. Relatively large inputs give a relatively good cotton production, whereas the food crops benefit in the next crop cycle from residual nutrients from fertilizer. In addition to the positive effect of the cash crops on the nutrient balance, they should also have a positive effect on farmers' income. However, this depends considerably on: world market supply and prices; market imperfections as a result of protection or buyers' quality requirements; and the national infrastructure and efficiency in product handling.

DATA PROBLEMS

Macrolevel

Macrolevel spatial data were amply available as a consequence of the many global and continental maps compiled in recent years. The following continental data were available: soil map of the world (FAO/UNESCO, 1997), land cover map (USGS *et al.*, 2000), DEM from the HYDRO1k geographic database (USGS, 1998), rainfall map (Leemans and Cramer, 1991), irrigation map (Döll and Siebert, 1999), cattle density map and small-ruminant density map (FAO, 2001a), poultry density map and a Harmattan deposition map. These data enabled spatially explicit calculations of most nutrient inflows and outflows. Only for mineral fertilizers

(IN1), and to a lesser extent crop products (OUT1) and crop residues (OUT2), was it necessary to divide national values evenly over the country because no spatial data were available.

The data were of differing quality. For example, the DEM has a resolution of 1 km, is based on satellite measurements and can be considered as high quality. The land cover map also has a resolution of 1 km and is based on satellite images of 1992–93, but these images had to be classified and the resulting maps are disputable. The classified maps should be checked locally in the field. However, this has not been done on a large scale. These maps are based on primary data, but other maps, e.g. the livestock-density maps, are derived from secondary sources, such as climate, soil and human population (FAO, 2001a). The Harmattan deposition map is the most inaccurate map because it is based on limited data from literature, which have been interpolated according to global wind patterns. However, these maps and data are probably the best available.

The accuracy of the tabular data also differs. FAOSTAT data rely on national statistics of differing quality. The quality of the statistics for Ghana and Mali is medium and for Kenya low according to FAO (http://faostat.fao.org/abcdq/about.htmx). All the crop data were based on sample surveys and not on total census data. Livestock data were normally better registered and available as total census data.

The quality of regression models, used to calculate leaching and gaseous losses, is always subject to debate. This is because such models are based on a limited data set, and they are not intended for use outside their own boundaries. The boundaries for the N-leaching regression model are: 40–2 000 mm rainfall, 3–54 percent clay content and 0.25–2 m layer thickness, based on 100 measurements (De Willigen, 2000). For the K-leaching regression model, only 26 measurements were available (which limited the borders): 1.3–8.1 cmol/kg for the CEC, 211–2 420 mm for rainfall, and 0–273 kg/ha for the amount of fertilizer.

Mesolevel

Data availability at the mesolevel was much lower than at the macrolevel because not all data are collected at district or province level. Moreover, the area was often too large for a representative farm survey. Spatial data at a representative scale were not available or were difficult to obtain. Most soil data were derived from national maps with scales of 1:250 000 (Ghana) or 1:1 000 000 (Kenya). These did not provide sufficient detail at the mesolevel or there were no related quantitative soil properties.

Land-use maps are generally not available at the mesolevel, making it difficult to use the procedure developed for the macrolevel. Moreover, this procedure is based on crop suitabilities. At the mesolevel, other factors such as management and land-use history are more important and they are necessary in order to make the level useful. The macrolevel grid resolution of 1 km would also be too coarse for the mesolevel. Aerial photographs and satellite imagery would be very useful, but are not always available.

Of all the data required, data on fertilizer use were the most difficult to obtain. Often, only recommended fertilizer rates were available (Kenya). Such rates are often greater than the actual application rates. Alternatively, it is possible to downscale national statistics, as was done for Ghana. In Mali, survey data were available, but their validity for the whole CMDT region was unknown because the distribution of the sample points was unknown. The quality of the data was not always reliable. Errors emerged by comparing such data with those obtained at the macrolevel. For example, the calculated yield, based on production and harvested area, should not be very different from the FAOSTAT data. This type of error occurred frequently and usually stemmed from typing errors, e.g. 12 000 kg/ha instead of 1 200 kg/ha maize.

Microlevel

The microlevel analysis used only farm survey data, combined with regression models. The quality of the data was normally good, but the representativeness of selected farms for the mesolevel was not easy to establish. Only a selection of the farms was surveyed, while variation is greatest at the microlevel. For example, the variability of soil properties between the different farms in one AEZ was larger than the variation between the different AEZs, as resulted from the VARINUTS study in Embu District (Table 34; SC-DLO *et al.*, 2000). Spatial data are often available at the microlevel or are relatively easy to create. With the help of the farmer, it is possible to make a soil or crop map quickly because the area is small. However, surveying and monitoring a representative sample in a mesolevel unit involves costs: researcher and farmer time and money.

MODELLING PROBLEMS

Land-use map

The land-use map was based on crop suitabilities. This means that crops with the greatest requirements were allocated to the best locations and that crops with lower requirements were used to fill up the remaining grid cells. This ideal situation may differ considerably from reality because of socio-economic, demographic and political factors. While a map based on remote-sensing data would be better, such maps are often unavailable. Where they are available, classification of the images is difficult and often subjective. Moreover, it is necessary to perform many field checks in order to ensure an accurate and reliable land-use map. The regional distribution of the crops is more important than the accuracy of the individual grid cell. This is because of the subsequent aggregation of the grid cells before presenting the final results. The quality of the land-use map depends on the quality of the input data, which vary considerably from country to country. New initiatives, such as Africover (http://www.africover.org), offer alternatives for the land cover map, which is the most important input. The multipurpose land cover database is based on better and more recent satellite images, has been checked thoroughly in the field and has a more specific legend. However, it was not available for the present study.

The land-use map procedure included a 5-km grid in order to prevent large land units, which would otherwise appear in areas with little variation in altitude, climate, land cover and soils. This meant that the largest possible land unit was 2 500 ha. This approach cannot simulate multiple cropping systems very well because each land unit can only be allocated to one crop. However, aggregation of the final results does give an average for multiple cropping systems. Crops with smaller harvested areas might not receive a proper distribution because of the large grid size of the land unit. While the use of a higher resolution, e.g. 1 km, can improve the distribution, this might make the processing time too lengthy because of the large data sets. Another problem arises for countries with considerable variation in topography, such as Kenya. The global data sets describing climate and growing periods are too approximate for such a country. The simulated land-use pattern for Kenya is quite angular at the eastern side and coincides exactly with the rainfall and growing-period map. Moreover, potato is shown as growing at too low altitudes in this area because temperature data have been interpolated without taking altitude into account.

Erosion modelling

The results of erosion modelling with the LAPSUS model require careful interpretation. The model was developed at the watershed level and is now used at the national level. The spatial resolution used for this study was 1 km, while the original DEM resolution was 25 m. This resulted in an incorrect representation of the topography at the watershed scale because of the levelling out of features such as small valleys. Therefore, a 1-km grid is representative for landscape scale at national and continental level. Other processes, such as river incisions, become more important at this higher scale level, while processes such as re-sedimentation and tillage erosion are lost at the macrolevel (Okoth, 2003). Nonetheless, the results were promising and the erosion-sedimentation patterns were simulated correctly, according to the field observations. A problem is verification of the results at this national-scale level. At a watershed level, one can try to measure erosion for the whole area, a difficult undertaking in itself. It is impossible to measure erosion at a national level, one can only collect as many data as possible and make an estimate for the whole country. This means that until now the only way to verify the model has been through expert knowledge.

Soil depth and the soil erodibility factor (K factor) are derived from estimates and scarce literature data. Although not a measurable variable, the K factor is used as a calibration parameter. Therefore, the absolute value of the K factor is rather subjective. However, the relative difference between each soil type is the most important aspect. Management is one of the main factors affecting erosion on agricultural land. However, it is not possible to incorporate this factor at this macrolevel because each land use is treated the same for the whole country.

In view of the above considerations, the resulting grid cells should be aggregated to a larger cell size, e.g. 10 km. The model cannot predict exactly the amount of erosion within a specific grid cell, but it can provide a good estimate at the regional scale. Nevertheless, this is currently the most useful model for quantitative erosion estimates at national and regional scale. The model determines erosion and sedimentation at the landscape scale and simulates natural runoff patterns. The dynamic character of the model generates a more realistic erosion-sedimentation pattern. It is necessary to conduct further research in order to improve the verification of these models and there needs to be a greater focus on the scale-level discussions.

Nutrient-balance calculations

This study used the program MS Access to calculate the nutrient balance at the macrolevel and the program ArcView to create the maps. A database program is most appropriate for handling large amounts of different data and making simple calculations. MS Access has the option to create user-friendly input forms and is also widely available for future users in developing countries. However, the use of MS Access has some drawbacks. Its database structure means that it treats all grids in the same way. Thus, it is difficult to make exceptions. MS Access is not powerful enough for countries with many different grid cells because the program has a limited processing capacity. In this study, it was not possible to automate the procedure entirely because queries had to be converted to tables for the ultimate summation of all flows.

The study used the program MS Excel for the microlevel and mesolevel calculations. This was because: (i) the calculation did not involve a large amount of data; and (ii) it was necessary to make more exceptions for specific crop management. Management is much more important at the microlevel and mesolevel, which results in many exceptions. Therefore, manual input is more appropriate as this facilitates small adaptations. A drawback of spreadsheets is data management; overview is lost easily when many data are involved. Database programs are easier for data management and help reduce the number of errors that are introduced.

SHORTCOMINGS AND CAVEATS

On 17 and 18 February 2003, a workshop took place in Nairobi. This workshop brought together a group of soil fertility experts and mesolevel stakeholders to discuss the results of this study. The objectives were: (i) to jointly review the study; (ii) to share experiences on the macrolevel, mesolevel and microlevel; and (iii) to reach conclusions on the suitability of the approach for the normative programme of FAO. Twenty-six participants working in small groups discussed the study at each scale level and presented related research. The general opinion of the workshop was that nutrient balances are a useful tool for specific users at the different scale levels. The following sections provide more detail on specific comments and recommendations that emerged at the workshop.

Validation

A major point raised at the workshop concerned the lack of sufficient validation and the considerable uncertainties attached to the different nutrient flows. Large-scale and data-demanding studies are difficult to validate because of the large areas and the large amounts of different data. This makes validation in the field very difficult and expensive. At the macrolevel, it is not possible to validate all the nutrient flows because this would require a massive number of samples. It might be possible to validate each nutrient flow at the microlevel, but these validations would then need scaling up to the mesolevel and the macrolevel. Other large-scale studies in the context of climate change and biodiversity research have similar, inherent validation problems. Although experiments are a relatively simple way of validating some nutrient flows, such as leaching, other flows, such as erosion or mineral fertilizer application, are much more difficult to validate. As it is almost impossible to validate the whole nutrient balance, one can choose to validate only those specific flows that are considered most important. For example, one can measure erosion in the field where this is one of the main losses according to the nutrient balance. These field observations and measurements should be performed according to a sound sampling scheme. Connecting the validations of process research, e.g. studies of N_2O losses, to system research, such as this study, is both practical and feasible.

Gaps

Although the nutrient balance includes the most important nutrient flows, it fails to take some aspects into account. At the macrolevel, it does not incorporate large-scale processes such as forest burning and river-basin sediment transport. At the livestock level, it does include urine specifically although its nutrient content is quite different from that of dung. In addition, nutrient losses from urine are very large because of leaching and volatilization. Some other aspects, although not directly linked with the nutrient balance, can be of importance for the functioning of the whole agro-ecosystem. For example, belowground biodiversity has a direct effect on soil structure and the release of nutrients from organic material. Off-site effects, such as sedimentation into reservoirs and excessive nitrate leaching to groundwater, can also be related to the nutrient balance. Depending on the definition of the system, transnational imports and exports of products can be important flows in the nutrient balance, e.g. export of cash crops and import of fertilizers. Economic dynamics, such as the withdrawal of subsidies or trade liberalization effects, provide the all-important context that needs to be known before suggesting any improved nutrient management. Finally, it may be necessary to examine nutrients other than N, P and K, such as calcium and sulphur, or organic carbon to link up with carbon sequestration research groups.

Specific problems for each scale level

In nutrient-balance calculations, each scale level has its own specific problems. At the macrolevel, the most important problems are: data quality; map interpretation;

resolution differences; and groundtruthing. Intensive field checks in accordance with a sound sampling scheme can provide a partial solution. Soil properties and nutrient stocks might also be collected with new techniques for rapid estimation by reflectance spectroscopy (Shepherd and Walsh, 2002). At the mesolevel, the main problems are: lack of spatial data; incorporation of different management systems; and the absence of socio-economic explanatory factors, e.g. credit facilities and marketing. Spatial data will be increasingly available in the future. A classified satellite image and a DEM will improve the mesolevel nutrient balance significantly. At the microlevel, much research has already been done. The NUTMON-toolbox is a useful application, which also includes the monetary part (www.nutmon.org). The issues at this level are: how to deal with diversity between and within farms; how to incorporate INM and integrated soil fertility management (ISFM) techniques; and how to scale up results. Possible options are: stratification in sampling methods; INM techniques in farmer field schools; and the use of GIS for upscaling.

Presentation of outcomes

Model results expressed in terms of kilograms of nutrient per hectare are not very meaningful for policy-makers. They prefer outcomes expressed in terms of yield loss or in monetary values. The nutrient balance should have links to other tools and data in order to make it more useful. Combining a simple soil fertility/crop production model, such as the quantitative evaluation of the fertility of tropical soils or QUEFTS (Janssen *et al.*, 1990), with the nutrient balance makes it possible to express nutrient depletion in terms of yield loss. Other attractive indicators to possibly attach to the nutrient flows and balance are the nutritive value of diets, food and cash needs, and equity indicators. Other options are to make use of decision-support systems and scenario studies. One way of making the nutrient-balance model more interactive is to link it to a model such as that of the conversion of land use and its effects (CLUE) (Veldkamp and Fresco, 1996), which simulates land-use changes and its effects. It is also possible to combine the results with other GIS data, such as food security or poverty maps.

Usefulness for policy-makers

It is important that policy-makers be aware of any gaps in the nutrient balance, so they know what the limitations of the nutrient balance model are. This raises the question of whether present outputs can serve as tools for policy-makers or whether further research is required. The nutrient-balance model proved to be a useful indicator for informed policy-makers, but the results as presented so far offer no entry points for intervention. The model raises awareness of soil fertility problems, indicates areas with nutrient depletion or accumulation, and gives a quantified picture of the nutrient flows at the macrolevel. At the mesolevel, it is possible to: (i) identify specific constraints; (ii) use quantified nutrient flows for planning purposes; and (iii) extrapolate results to other similar areas. Furthermore, outcomes might convince policy-makers to make action plans to improve soil fertility.

IMPACT

Any assessment of the impact of a negative nutrient balance needs to consider the actual soil fertility, i.e. the nutrient stocks. A negative nutrient balance on a rich soil will not affect yield in the short term, while crop yield on a poor soil may decline each year as a result of nutrient depletion. At some stage, a negative nutrient balance may no longer affect production in marginal areas. This may be the case when yields depend on natural inputs, such as IN3, to make up for any minimal losses.

The declines in yield and N stocks are most significant in the initial decades and then they begin to level off. Figure 30 shows that yields on a rich soil remain unaffected for a much longer time. Hence, one could say that nutrient depletion often does not manifest itself clearly, but problems are likely to occur for the 'future generations' of the Brundtland definition (Brundtland, 1987).

In this example, the yield decline is related with the decline in N stocks. For a better simulation, a crop growth model should be linked to the nutrient depletion model. QUEFTS (Janssen *et al.*, 1990) may be suitable as it is relatively simple to use and takes the interaction between N, P and K into account.

It is also possible to express declines in yield and nutrient stocks in economic terms. In this case, yield decline is a private (farmer) cost, whereas the decline in nutrient stocks is a social cost. The nutrient stock estimates in this study (Annex 6) were based on data sets from the 1970s and 1980s. This may imply that the actual stocks are probably lower.

Farmers will normally adjust their management when they experience yield decline. Where they do not have the means to increase fertilizer or manure use, they may try to make better use of low-cost integrated nutrient management technologies (e.g. tree-crop mixtures, green manures, rock phosphate, soil and water conservation, niche management, benefiting from soil microvariability).

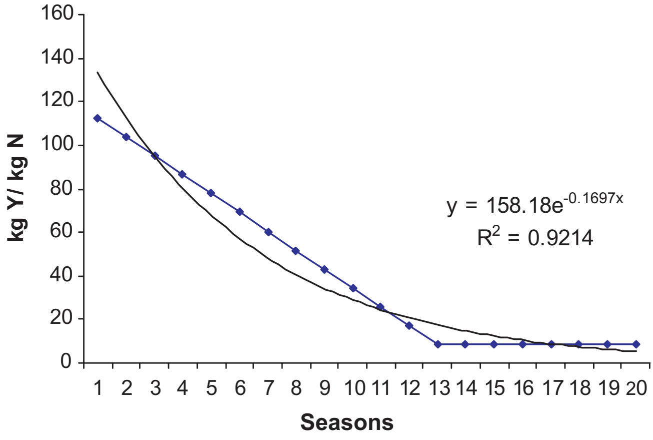
Depletion of the natural N stock of a soil causes a decline in the efficiency of fertilizer use. As N nutrient depletion progresses over time, N fertilizer application needs to increase to maintain yields, i.e. the ratio kg N fertilizer / kg Y increases. It is assumed that the opportunity cost of decreasing fertilizer productivity over time represents the value of soil N decline.

A dynamic model was used to estimate the costs of nutrient depletion. The model was linked to a biophysical model that simulated the effects of nutrient balance changes in the farming systems of Ghana (2), Tanzania and Mali.

Seasonal N stocks in the soils were used to estimate yield changes over time, yields being a dependent variable of nitrogen availability (Figure 30). When N removal became equivalent to N input, yields were assumed to stabilize (at a low level) for the remaining seasons in the period of 20 years. The crop and site-specific fertilizer use efficiency decline was estimated using an e-log function, i.e. $NFP = b \times e^{-t}$ where: NFP = nitrogen fertilizer productivity, and t = time. The integral of the function over 20 years estimated the decline in N fertilizer use efficiency as the result of soil N removal:

$$NFP_{loss} = \sum_{t=0}^{t=20} b \times e^{-t}$$

FIGURE 30
Maize fertilizer productivity loss, Kenya



Costs were computed for every crop in each farming system and expressed per hectare of crop. These costs were adjusted for the area cropped within the farming system to arrive at a "weighted" cost. The total costs of N nutrient depletion were computed by the sum of two components: the opportunity cost of production losses due to yield decline, potential yields were assumed to grow at 1 percent per year, and the costs of the permanent impact of reduced N fertilizer productivity within each farming system as a proxy for the decline in soil N stocks (Table 47). The net present values per hectare of "farming system" were discounted at 10 percent per annum.

The result suggests that the cost of N fertilizer productivity is higher than the cost of yield reduction in the Embu and Koutiala cropping systems. The opportunity cost of production losses due to yield decline constitutes foregone farm income; the decline in fertilizer use productivity is a directly incurred production cost by the farmers. Addressing the nutrient exchange capacity of soils will not only protect farmers' future income, it will also prevent an adverse effect on the competitiveness of the production systems caused by higher fertilization cost. The latter is of particular relevance for farmers operating in an increasingly integrated global market. The cost of addressing soil fertility decline constitutes an attractive intervention in the districts in Ghana and Kenya and to a lesser extent in Mali. The cost involved could vary between US$70/ha in Mali and US$1 500/ha in Kenya, with a possible share to be financed by farmers between 10 and 70 percent.

TABLE 47
Nutrient depletion benefits and cost, US$/ha

	Nkawie, Ghana	Wasa Amenfi, Ghana	Embu, Kenya	Koutiala, Mali
	(US$/ha)			
Yield losses	224	592	490	28
Soil N exchange capacity reduction	79	43	1 035	39
Total cost	303	635	1 525	67
Benefits	1 909	3 351	2 849	49
Benefit/cost	6.3	5.3	1.9	0.7

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Annex 1

Nutrient content values of manure from literature

Values based on fresh matter; dry matter assumed to be 50 percent of fresh matter

Cattle manure	**N (%)**	**P (%)**	**K (%)**	
	0.70	0.30	0.67	Lekasi *et al.*, 2001a
	1.63	0.09	1.13	Smaling *et al.*, 1999
	0.57	0.14		FAO, 1980
	0.64	0.06	0.23	Williams *et al.*, 1995
	0.79	0.22	1.00	Baijukya *et al.*, 1998
	0.29	0.03	0.42	Budelman and Defoer, 2000
	0.70	0.26	0.55	Budelman and Defoer, 2000
Average:	0.76	0.15	0.67	
Sheep/goat manure	N (%)	P (%)	K (%)	
	0.75	0.20	0.69	Lekasi *et al.*, 2001a
	0.75	0.11		FAO, 1980
	0.60	0.22	0.54	Indian Council of Agricultural Research, 1997
	1.10	0.06	0.37	Williams *et al.*, 1995
	0.20	0.10	0.35	Budelman and Defoer, 2000
	0.65	0.20	0.50	Budelman and Defoer, 2000
	1.45	0.53	0.53	Budelman and Defoer, 2000
Average:	0.79	0.20	0.50	
Poultry manure	N (%)	P (%)	K (%)	
	0.67	0.30		FAO, 1980
	1.40	0.70	0.71	Indian Council of Agricultural Research, 1997
	0.65	0.40	0.15	Budelman and Defoer, 2000
	1.60	0.15	0.18	Budelman and Defoer, 2000
Average:	1.08	0.39	0.35	
Animal manure	N (%)	P (%)	K (%)	
	0.56	0.15	0.12	Lekasi *et al.*, 2001b
	0.84	0.12		Eyasu, 1998
	0.70	0.11		Eyasu, 1998
	0.70	0.10		Eyasu, 1998
	0.60	0.10	0.77	Kater *et al.*, 2000
	0.39	0.10	0.63	Onduru *et al.*, 1999
	0.70	0.25	0.55	Van den Bosch *et al.*, 1998a
	0.54	0.09	0.65	Defoer *et al.*, 1998
	0.54	0.16	0.72	Average of Stoorvogel and Smaling, 1990
Average:	0.63	0.13	0.54	

Annex 2

Reference values for K-leaching regression model

The model is based on 33 representative experiments and has an R^2 value of 0.45.

Reference	Country	Crop	CEC	K fert.	Rainfall	K leach.
			cmol/kg	kg K/ha	mm	kg K/ha
Hafner *et al.*, 1992	Niger	Millet	1.3	0	699	12
Hafner *et al.*, 1992	Niger	Millet	1.3	25	699	10
Van der Eijk, 1995	Tanzania	Bananas/beans	4.6	0	2 000	39
Van der Eijk, 1995	Tanzania	Bananas	4.6	273	724	74
Wong *et al.*, 1992	Nigeria	Maize	2.4	67	2 420	23
Wong *et al.*, 1992	Nigeria	Rice (upland)	2.4	42	2 420	9
Wong *et al.*, 1992	Nigeria	Bare soil	2.4	67	2 420	29
Wong *et al.*, 1992	Nigeria	Bare soil	2.4	42	2 420	20
Imbach *et al.*, 1989	Costa Rica	Cacao/poro	-	27	1 923	1
Imbach *et al.*, 1989	Costa Rica	Cacao/laurel	-	27	1 923	1
Gigou, 1986	Cameroon	Sorghum/cotton	7.4	62	737	2
Chabalier, 1984	Côte d'Ivoire	Maize	8.0	29	633	1
Chabalier, 1984	Côte d'Ivoire	Maize	8.0	58	633	1
Chabalier, 1984	Côte d'Ivoire	Cotton	8.0	37	532	1
Chabalier, 1984	Côte d'Ivoire	Cotton	8.0	75	532	1
Chabalier, 1984	Côte d'Ivoire	Maize	8.0	29	633	2
Chabalier, 1984	Côte d'Ivoire	Maize	8.0	58	633	2
Chabalier, 1984	Côte d'Ivoire	Cotton	8.0	37	532	2
Chabalier, 1984	Côte d'Ivoire	Cotton	8.0	75	532	1
Roose, 1981	Côte d'Ivoire	Maize	8.0	39	2 100	3
Roose, 1981	Côte d'Ivoire	Rubber	8.1	0	2 100	63
Roose, 1981	Côte d'Ivoire	Tree savannah (burned)	6.1	0	1 350	21
Roose, 1981	Côte d'Ivoire	Maize	6.1	70	1 350	1
Roose, 1981	Burkina Faso	Fallow	2.5	0	860	4
Roose, 1981	Burkina Faso	Sorghum	2.5	50	860	1
Roose, 1981	Burkina Faso	Tree savannah	3.9	0	860	1
Cisse, 1986	Senegal	Groundnut	5.2	34	211	3
Cisse, 1986	Senegal	Groundnut	6.3	34	211	1
Cisse, 1986	Senegal	Groundnut	5.2	34	279	1
Cisse, 1986	Senegal	Groundnut	5.2	34	347	2
Cisse, 1986	Senegal	Millet	5.2	9	347	1
Cisse, 1986	Senegal	Millet	6.3	9	347	0
Charreau, 1972	Senegal	Rotation	-	0	660	7

Annex 3

Rooting depth

Crop	Rooting depth (m)*
Banana	0.5
Barley	1.0
Cassava	0.6
Citrus	1.1
Cocoa	0.7
Coconut	1.0
Coffee	0.9
Cotton	1.0
Fallow	0.5
Fibres	0.8
Fodder	0.8
Groundnut	0.5
Maize	0.9
Millet	1.0
Oil-palm	1.0
Other cereals	1.0
Other fruits	1.0
Other oil crops	1.0
Other roots	0.5
Plantains	0.5
Potato	0.4
Pulses	0.6
Rice	0.5
Rubber	1.0
Sesame	1.0
Sorghum	1.0
Soybeans	0.6
Sugar cane	1.2
Sunflower	0.8
Sweet potato	1.0
Tea	0.9
Tobacco	0.7
Vegetables	0.4
Wheat	1.0

* Minimum value of maximum rooting depth used in order to prevent overestimation.
Source: FAO (1998b).

Annex 4

Reference values for gaseous losses

Reference values for NH_3 emission

Reference	Location	Crop	N fertilizer (kg N/ha)	NH_3 emission (kg N/ha)	NH_3 loss (% of N fert.)
McKenzie and Tainton, 1993	South Africa	grass	50	1.4	0.027
McKenzie and Tainton, 1993	South Africa	grass	100	3.7	0.037
Praveen-Kumar and Aggarwal, 1988	Jodhpur, India	bare	40	5.8	0.145
Praveen-Kumar and Aggarwal, 1988	Jodhpur, India	bare	40	5.2	0.130
Praveen-Kumar and Aggarwal, 1988	Jodhpur, India	bare	40	3.2	0.080
Praveen-Kumar and Aggarwal, 1988	Jodhpur, India	bare	40	4.4	0.110
Praveen-Kumar and Aggarwal, 1988	Jodhpur, India	bare	40	4.4	0.110
Praveen-Kumar and Aggarwal, 1988	Jodhpur, India	bare	40	2.4	0.060
Praveen-Kumar and Aggarwal, 1988	Jodhpur, India	bare	40	3.2	0.080
Praveen-Kumar and Aggarwal, 1988	Jodhpur, India	pearl millet	40	5.5	0.137
Praveen-Kumar and Aggarwal, 1988	Jodhpur, India	pearl millet	40	2.3	0.057
Praveen-Kumar and Aggarwal, 1988	Jodhpur, India	pearl millet	40	3.6	0.090
Praveen-Kumar and Aggarwal, 1988	Jodhpur, India	pearl millet	40	4.1	0.104
Praveen-Kumar and Aggarwal, 1988	Jodhpur, India	pearl millet	40	4.4	0.110
Fan *et al.*, 1996	Dehradun, India	bare	100	18.7	0.187
Fan *et al.*, 1996	Dehradun, India	bare	100	17.9	0.179
Fan *et al.*, 1996	Dehradun, India	bare	100	16.8	0.168
Fan *et al.*, 1996	Dehradun, India	bare	100	15.9	0.159
Fan *et al.*, 1996	Dehradun, India	bare	100	13.4	0.134
Fan *et al.*, 1996	Dehradun, India	bare	100	10.9	0.109
Fan *et al.*, 1996	Dehradun, India	bare	100	8.7	0.087
Fan *et al.*, 1996	Delhi, India	bare	100	24.8	0.248
Fan *et al.*, 1996	Delhi, India	bare	100	20.3	0.203
Fan *et al.*, 1996	Delhi, India	bare	100	15.8	0.158
Fan *et al.*, 1996	Delhi, India	bare	100	11.4	0.114
Fan *et al.*, 1996	Delhi, India	bare	100	18.9	0.189
Fan *et al.*, 1996	Delhi, India	bare	100	17.5	0.175
Fan *et al.*, 1996	Delhi, India	bare	100	13.5	0.135
Fan *et al.*, 1996	Delhi, India	bare	100	13.2	0.132
Fan *et al.*, 1996	Delhi, India	bare	100	15.6	0.156
Fan *et al.*, 1996	Delhi, India	bare	100	9.8	0.098
Patel and Mohanty, 1989	Cuttack, India	rice	30	0.5	0.016
Patel and Mohanty, 1989	Cuttack, India	rice	15	0.2	0.014
Patel and Mohanty, 1989	Cuttack, India	rice	15	0.2	0.014
Patel and Mohanty, 1989	Cuttack, India	rice	15	0.3	0.019
Patel and Mohanty, 1989	Cuttack, India	rice	15	0.3	0.020
Patel and Mohanty, 1989	Cuttack, India	rice	15	0.1	0.008
Patel and Mohanty, 1989	Cuttack, India	rice	15	0.2	0.012
Patel and Mohanty, 1989	Cuttack, India	rice	60	1.6	0.026
Patel and Mohanty, 1989	Cuttack, India	rice	60	1.2	0.021
Patel and Mohanty, 1989	Cuttack, India	rice	60	1.8	0.031

Reference	Location	Crop	N fertilizer (kg N/ha)	NH_3 emission (kg N/ha)	NH_3 loss (% of N fert.)
Dhyani and Mishra, 1992	Pantnagar, India	bare	0	5.6	
Dhyani and Mishra, 1992	Pantnagar, India	bare	60	14.4	0.240
Dhyani and Mishra, 1992	Pantnagar, India	bare	60	9.9	0.164
Dhyani and Mishra, 1992	Pantnagar, India	bare	60	8.3	0.139
Dhyani and Mishra, 1992	Pantnagar, India	bare	60	9.7	0.161
Dhyani and Mishra, 1992	Pantnagar, India	bare	60	12.3	0.204
Dhyani and Mishra, 1992	Pantnagar, India	bare	60	10.0	0.167
Dhyani and Mishra, 1992	Pantnagar, India	bare	60	11.3	0.189
Dhyani and Mishra, 1992	Pantnagar, India	bare	120	21.5	0.180
Dhyani and Mishra, 1992	Pantnagar, India	bare	120	17.4	0.145
Dhyani and Mishra, 1992	Pantnagar, India	bare	120	12.5	0.104
Dhyani and Mishra, 1992	Pantnagar, India	bare	120	17.2	0.144
Dhyani and Mishra, 1992	Pantnagar, India	bare	120	18.9	0.158
Dhyani and Mishra, 1992	Pantnagar, India	bare	180	28.4	0.158
Dhyani and Mishra, 1992	Pantnagar, India	bare	240	31.2	0.130
Palma *et al.*, 1997	Buenos Aires, Argentina	maize		0.5	
Palma *et al.*, 1997	Buenos Aires, Argentina	maize	60	7.4	0.123
Palma *et al.*, 1997	Buenos Aires, Argentina	maize	60	5.3	0.088
Palma *et al.*, 1997	Buenos Aires, Argentina	maize		0.5	
Palma *et al.*, 1997	Buenos Aires, Argentina	maize	60	5.66	0.094
Palma *et al.*, 1997	Buenos Aires, Argentina	maize	60	3.74	0.062
Aggarwal *et al.*, 1987	Jodhpur, India	bare	40	3.6	0.090
Aggarwal *et al.*, 1987	Jodhpur, India	bare	80	12.0	0.150
Aggarwal *et al.*, 1987	Jodhpur, India	bare	120	27.6	0.230
Aggarwal *et al.*, 1987	Jodhpur, India	prosopis trees	40	2.6	0.065
Aggarwal *et al.*, 1987	Jodhpur, India	prosopis trees	80	7.6	0.095
Aggarwal *et al.*, 1987	Jodhpur, India	prosopis trees	120	18.0	0.150
Aggarwal *et al.*, 1987	Jodhpur, India	prosopis trees	80	12.1	0.151
Aggarwal *et al.*, 1987	Jodhpur, India	prosopis trees	80	9.3	0.116
Aggarwal *et al.*, 1987	Jodhpur, India	prosopis trees	80	6.7	0.084
Aggarwal *et al.*, 1987	Jodhpur, India	prosopis trees	80	2.8	0.035
Aggarwal *et al.*, 1987	Jodhpur, India	prosopis trees	80	0.8	0.010

Reference values for N_2O emission

Reference	Crop	Org. C (%)	Precipitation (mm)	N fertilizer (kg N/ha)	N_2O emission (kg N/ha)
Ortiz-Monasterio *et al.*, 1996	Wheat, irrigated			250	3.2
Ortiz-Monasterio *et al.*, 1996	Wheat, irrigated			250	1.5
Mosier and Delgado, 1997	Grass	2.8	1 120	0	1.43
Mosier and Delgado, 1997	Grass	2.8	1 120	300	11.4
Mosier and Delgado, 1997	Grass	3.7	1 930	0	1.38
Mosier and Delgado, 1997	Grass	3.7	1 930	300	3.84
Mosier and Delgado, 1997	Grass	2.1	1 650	0	1.647
Mosier and Delgado, 1997	Grass	2.1	1 650	300	4.012
Mosier *et al.*, 1998	Sorghum	2.1	1 650	0	1.37
Mosier *et al.*, 1998	Sorghum	2.1	1 650	0	0.44
Mosier *et al.*, 1998	Sorghum	2.1	1 650	0	0.309
Mosier *et al.*, 1998	Sorghum	2.1	1 650	150	0.938
Mosier *et al.*, 1998	Sorghum	2.1	1 650	0	0.84
Mosier *et al.*, 1998	Sorghum	2.1	1 650	0	0.336
Mosier *et al.*, 1998	Sorghum	2.1	1 650	0	0.497
Mosier *et al.*, 1998	Sorghum	2.1	1 650	100	1.57
Mosier *et al.*, 1998	Sorghum	2.1	1 650	0	0.903
Mosier *et al.*, 1998	Sorghum	2.1	1 650	300	5.998
Mosier *et al.*, 1998	Sorghum	2.1	1 650	0	0.762
Mosier *et al.*, 1998	Sorghum	2.1	1 650	300	2.54
Mosier *et al.*, 1998	Sorghum	2.1	1 650	0	1.03
Mosier *et al.*, 1998	Sorghum	2.1	1 650	100	7.19
Matson *et al.*, 1996	Sugar cane	1.6	1 250	84	0.011
Matson *et al.*, 1996	Sugar cane	1.5	1 125	34	0.11
Matson *et al.*, 1996	Sugar cane		1 125	22	0.013
Matson *et al.*, 1996	Sugar cane	1.5	275	45	0.052
Matson *et al.*, 1996	Sugar cane	1.5	275	35	0.17
Matson *et al.*, 1996	Sugar cane		275	39	0.092
Matson *et al.*, 1996	Sugar cane		275	20	0.006
Matson *et al.*, 1996	Sugar cane	8	1 100	95	0.38
Matson *et al.*, 1996	Sugar cane	5.6	3 810	124	1.25
Matson *et al.*, 1996	Sugar cane	5.5	3 800	94	0.33
Mahmood *et al.*, 1998	Maize, irrigated	1.1	340	100	0.16
Mahmood *et al.*, 1998	Wheat, irrigated	1.1	340	100	0.49
Veldkamp *et al.*, 1998	Grass		3 962	0	2.3
Veldkamp *et al.*, 1998	Grass		3 962	0	4.3
Veldkamp *et al.*, 1998	Grass		3 962	300	22.6
Veldkamp *et al.*, 1998	Grass		3 962	300	
Veldkamp *et al.*, 1998	Grass		3 962	300	
Veldkamp *et al.*, 1998	Grass		3 962	300	
Veldkamp *et al.*, 1998	Grass		3 962	300	
Veldkamp and Keller, 1997	Banana		3 962	360	
Veldkamp and Keller, 1997	Banana		3 962	360	
Veldkamp and Keller, 1997	Banana		3 962	360	6.1
Freney *et al.*, 1981	Rice, flooded		40	20	0.0
Watanabe *et al.*, 2000	Maize		1 150	0	0.119
Watanabe *et al.*, 2000	Maize		1 150	62.5	0.196
Watanabe *et al.*, 2000	Maize		1 150	0	0.109
Watanabe *et al.*, 2000	Maize		1 150	62.4	0.289

Reference	**Crop**	**Org. C (%)**	**Precipitation (mm)**	**N fertilizer (kg N/ha)**	**N_2O emission (kg N/ha)**
Watanabe *et al.*, 2000	Maize		1 150	0	0.122
Watanabe *et al.*, 2000	Maize		1 150	75	0.351
Watanabe *et al.*, 2000	Maize		1 150	0	0.1
Watanabe *et al.*, 2000	Maize		1 150	46.9	0.403
Suratno *et al.*, 1998	Rice, flooded	2.4		0	0.315
Suratno *et al.*, 1998	Rice, flooded	2.4		0	0.425
Suratno *et al.*, 1998	Rice, flooded	2.4		86	0.649
Suratno *et al.*, 1998	Rice, flooded	2.4		86	0.629
Suratno *et al.*, 1998	Rice, flooded	2.4		86	0.905
Suratno *et al.*, 1998	Rice, flooded	2.4		86	0.712
Suratno *et al.*, 1998	Rice, flooded	2.4		0	0.306
Suratno *et al.*, 1998	Rice, flooded	2.4		0	0.484
Suratno *et al.*, 1998	Rice, flooded	2.4		86	0.749
Suratno *et al.*, 1998	Rice, flooded	2.4		86	1.092
Suratno *et al.*, 1998	Rice, flooded	2.4		86	0.859
Suratno *et al.*, 1998	Rice, flooded	2.4		86	1.012
Bronson *et al.*, 1997a; b	Rice, flooded	1.7		120	1.802
Bronson *et al.*, 1997a; b	Rice, flooded	1.7		200	1.427
Bronson *et al.*, 1997a; b	Rice, flooded	1.7		120	1.948
Bronson *et al.*, 1997a; b	Rice, flooded	1.7		120	1.773
Bronson *et al.*, 1997a; b	Rice, flooded	1.7		120	0.741
Bronson *et al.*, 1997a; b	Rice, flooded	1.7		200	1.04
Bronson *et al.*, 1997a; b	Rice, flooded	1.7		120	0.835
Bronson *et al.*, 1997a; b	Rice, flooded	1.7		120	1.097
Bronson *et al.*, 1997a; b	Rice, flooded	1.7		120	0.452
Bronson *et al.*, 1997a; b	Rice, flooded	1.7		200	0.16
Bronson *et al.*, 1997a; b	Rice, flooded	1.7		120	0.181
Bronson *et al.*, 1997a; b	Rice, flooded	1.7		120	0.639
Bronson *et al.*, 1997a; b	Rice, flooded	1.7		112	0.831
Bronson *et al.*, 1997a; b	Rice, flooded	1.7		192	0.16
Bronson *et al.*, 1997a; b	Rice, flooded	1.7		112	0.181
Bronson *et al.*, 1997a; b	Rice, flooded	1.7		112	0.526
Weitz *et al.*, 1999	Balsa tree plantation	5.2		65	2.84
Crill *et al.*, 2000	Corn	7.5	3 962	0	0.51
Crill *et al.*, 2000	Corn	7.5	3 962	122	1.83
Crill *et al.*, 2000	Papaya	7.5	3 962	0	0.19
Crill *et al.*, 2000	Papaya	7.5	3 962	133	1.37

Reference values for NO_x emissions

Reference	Crop	Org. C (%)	Precipitation (mm)	N fertilizer (kg N/ha)	NO_x emission (kg N/ha)
Matson *et al.*, 1996	Sugar cane	1.6	1 250	84	0.01
Matson *et al.*, 1996	Sugar cane	1.5	1 125	34	0.00
Matson *et al.*, 1996	Sugar cane		1 125	22	0.01
Matson *et al.*, 1996	Sugar cane	1.5	275	45	0.01
Matson *et al.*, 1996	Sugar cane	1.5	275	35	0.00
Matson *et al.*, 1996	Sugar cane		275	39	0.01
Matson *et al.*, 1996	Sugar cane		275	20	0.00
Matson *et al.*, 1996	Sugar cane	8.0	1 100	95	1.95
Matson *et al.*, 1996	Sugar cane	5.5	3 800	94	0.71
Veldkamp *et al.*, 1998	Grass		3 962	0	0.82
Veldkamp *et al.*, 1998	Grass		3 962	0	1.13
Veldkamp *et al.*, 1998	Grass		3 962	300	4.64
Veldkamp *et al.*, 1998	Grass		3 962	300	8.38
Veldkamp *et al.*, 1998	Grass		3 962	300	7.48
Veldkamp *et al.*, 1998	Grass		3 962	300	5.41
Veldkamp *et al.*, 1998	Grass		3 962	300	6.97
Ortiz-Monasterio *et al.*, 1996	Wheat, irrigated			250	6.29
Ortiz-Monasterio *et al.*, 1996	Wheat, irrigated			250	2.71
Weitz *et al.*, 1999	Tree plantation			65	0.41
Cardenas *et al.*, 1993	Savannah	1.0		80	0.14
Cardenas *et al.*, 1993	Savannah	1.0		80	0.05
Cardenas *et al.*, 1993	Savannah	1.0		0	0.02
Rondon *et al.*, 1993	Savannah	0.9	1 300	0	0.01
Rondon *et al.*, 1993	Savannah	0.9	1 300	200	0.65
Rondon *et al.*, 1993	Savannah	0.9	1 300	200	0.06
Rondon *et al.*, 1993	Savannah	2.0	1 300	200	0.29
Veldkamp and Keller, 1997	Banana		3 962	360	10.70
Meixner *et al.*, 1997	Maize		846	0	0.34
Meixner *et al.*, 1997	Maize		846	16	1.10
Sanhueza *et al.*, 1994	Savannah	4.0		200	0.01
Sanhueza *et al.*, 1994	Savannah	4.0		200	0.20
Sanhueza *et al.*, 1994	Savannah	4.0		0	0.00
Skiba *et al.*, 1997	Grass	1.4		100	0.03
Skiba *et al.*, 1997	Grass	1.4		100	0.17
Skiba *et al.*, 1997	Grass	1.4		100	0.14
Skiba *et al.*, 1997	Grass	1.4		100	0.14

Annex 5

A procedure for LAPSUS modelling

The following sections describe the procedure used in a 2003 FAO study to estimate erosion–sedimentation for Ghana, Kenya and Mali.

The erosion–sedimentation modelling with LAPSUS used five different input maps (ASCII files): DEM, rainfall, infiltration, soil depth and soil erodibility (K factor).

DEM

The most important input was the DEM, used to derive the slope gradients. This DEM needed to be free of sinks and flats (neighbouring grid cells with exactly the same altitude). A new sinkless DEM has been created with ArcInfo (using the 'fill' command). With a special program (arc_flat.cpp), developed by Schoorl, this new DEM has eliminated flats by combining the sinkless DEM and a flow-direction map. This new flatless and sinkless DEM served as an input for the LAPSUS model.

RAINFALL

For rainfall, the LAPSUS modelling used the IIASA rainfall map with a resolution of 0.5 degrees (available for the whole of Africa). Within the model, an evaporation factor was set at 0.4 (which means that 60 percent of all rainfall evaporates). This factor might be different for each country. The IIASA map was not used for Kenya because it was too coarse and contained errors, e.g. the effect of Mount Kenya was not visible. Therefore, the study used a climate map by Corbett and White (1998). The IIASA rainfall map was adequate for Ghana and Mali because these countries have a less pronounced topography and a more regular rainfall pattern.

INFILTRATION

The amount of infiltration should be known in order to enable a good estimation of runoff. Infiltration is related to land cover and land use. The infiltration capacity determines the amount of rainfall that infiltrates and the part that runs off. Therefore, the land cover map with the International Geosphere-Biosphere Programme classification was reclassified into eight classes with the following infiltration percentages:

• Forest (1–5)	100 percent
• Shrublands (6–8)	70 percent
• Grasslands (9, 10)	85 percent
• Permanent wetlands (11)	100 percent

• Croplands (12, 14)	60 percent
• Urban and built-up (13)	60 percent
• Barren (16)	20 percent
• Water (17)	100 percent

Soil depth

Soil depth determines the available water storage capacity and is, therefore, important to estimating the amount of runoff. Each soil unit was classified according to soil-depth classes. The following classes were distinguished and used to create a soil-depth map:

1. > 1 m	1.2 m
2. 0.4–1 m	0.7 m
3. < 0.4 m	0.25 m
0. Water	2 m

K FACTOR

The amount of runoff can be calculated using the above input parameters. The erodibility of the soil (detachment factor) should be known in order to estimate the amount of erosion. Each soil unit was classified according to soil erodibility classes. These classes were based on work by FAO (2002) and expert knowledge. The soil-erodibility classes were reclassified to K factors (below) and exported to a grid map.

0. Water	1×10^{-6}
1. Very low	1×10^{-5}
2. Low	2×10^{-5}
3. Medium	3×10^{-5}
4. High	5×10^{-5}
5. Very high	1×10^{-4}

SIMULATION

The run-time of the LAPSUS model simulation was set at one year for this study. The model produced two output files: an ASCII file with runoff; and an ASCII file with the profile change in metres (net erosion-sedimentation). These files can be imported in ArcView and displayed. Further information about the LAPSUS model is available in Schoorl *et al.* (2002) and Schoorl and Veldkamp (2001).

Annex 6

Soil properties – FAO74 classification

FAO74	FAO unit	Clay %	pH	Org. C %	Tot. N %	Exch. K cmol/kg	CEC cmol/kg	Bulk kg/dm^3	Avail. P ppm	Erod.*	Depth*
Af	Ferric Acrisol	30.6	5	1.01	0.088	0.22	6.39	1.44	3.3	2	1
Ag	Gleyic Acrisol	17.9	4.7	2.16	0.119	0.40	9.56	1.41	1.5	3	2
Ah	Humic Acrisol	37.0	4.9	3.32	0.266	0.22	12.95	1.32	8.0	1	1
Ao	Orthic Acrisol	21.3	4.9	0.87	0.083	0.21	5.18	1.38	4.0	3	3
Ap	Plinthic Acrisol	19.2	4.7	1.34	0.141	0.11	5.11	1.53	4.5	4	1
Bc	Chromic Cambisol	23.5	6.9	0.71	0.069	0.78	11.66	1.33	5.5	3	1
Bd	Dystric Cambisol	24.7	5.1	1.27	0.118	0.33	9.32	1.27	5.7	3	1
Be	Eutric Cambisol	23.3	6.7	1.07	0.109	1.86	12.88	1.45	12.6	3	2
Bf	Ferralic Cambisol	27.8	5.1	0.88	0.073	0.52	6.64	1.28	2.3	3	1
Bg	Gleyic Cambisol	25.9	5.8	0.89	0.078	0.34	12.06	1.5	7.6	3	1
Bh	Humic Cambisol	42.1	5.1	5.01	0.402	0.25	16.87	1.15	2.0	1	1
Bk	Calcic Cambisol	26.6	8.1	0.76	0.106	0.85	19.79	1.45	4.3	3	1
Bv	Vertic Cambisol	40.5	6.9	0.95	0.097	0.83	25.27	1.41	2.0	4	2
Ch	Haplic Chernozem	50.0	7.7	2.19	0.260	0.10	35.80	1.42	3.0	1	1
Ck	Calcic Chernozem	40.7	8.1	0.89	0.100	1.25	22.61	1.37	3.3	1	1
Cl	Luvic Chernozem	27.8	7.6	0.81	0.090	0.68	13.01	1.65	3.1	1	1
E	Rendzinas	21.5	7.6	1.59	0.163	0.95	21.88	1.34	17.4	2	3
Fa	Acric Ferralsol	50.1	4.7	1.60	0.094	0.22	7.51	1.12	1.6	3	2
Fh	Humic Ferralsol	41.2	4.9	2.99	0.190	0.18	9.96	1.21	7.5	2	1
Fo	Orthic Ferralsol	37.0	5	1.44	0.108	0.24	8.33	1.4	4.1	2	2
Fp	Plinthic Ferralsol	31.5	4.9	1.29	0.077	0.25	5.83	1.31	4.3	3	3
Fr	Rhodic Ferralsol	46.7	5.5	1.31	0.103	0.29	8.57	1.25	4.6	3	2
Fx	Xanthic Ferralsol	27.3	4.5	1.00	0.067	0.09	5.62	1.26	4.3	4	2
G	Gleysols	42.3	5.7	1.51	0.151	1.09	20.60	1.38	5.2	2	1
Gc	Calcaric Gleysol	50.4	7.5	1.17	0.120	1.55	27.86	1.65	3.1	1	1
Gd	Dystric Gleysol	48.0	5	2.35	0.160	1.10	25.79	1.2	6.5	3	1
Ge	Eutric Gleysol	29.8	6.2	1.35	0.077	0.95	17.84	1.43	4.6	3	1
Gh	Humic Gleysol	34.8	5.1	5.18	0.381	0.25	16.38	1.45	4.4	1	1
Gm	Mollic Gleysol	48.3	6.6	2.51	0.243	1.58	29.18	1.44	6.6	1	1
Gp	Plinthic Gleysol	48.6	5.4	2.58	0.258	1.24	20.60	1.03	3.5	3	2
Hc	Calcaric Phaeozem	35.9	7.9	0.99	0.106	0.81	30.83	1.49	21.7	1	1
Hg	Gleyic Phaeozem	45.8	6	1.99	0.120	0.79	22.57	1.45	5.6	1	1
Hh	Haplic Phaeozem	39.5	6.4	2.42	0.222	1.18	28.12	1.43	21.0	2	1
Hl	Luvic Phaeozem	40.2	6.3	1.59	0.129	1.85	27.57	1.48	31.8	2	1
I	Lithosols	32.0	7.7	3.88	0.433	1.10	11.53	1.42	6.0	3	3
J	Fluvisols	31.8	7.5	0.70	0.070	0.77	14.80	1.4	11.3	2	1
Jc	Calcaric Fluvisol	25.7	8.1	0.83	0.077	1.29	27.45	1.45	9.2	1	1
Jd	Dystric Fluvisol	36.3	4.8	1.88	0.158	0.18	15.04	1.36	11.6	2	1
Je	Eutric Fluvisol	22.3	7	1.07	0.116	0.63	12.51	1.42	13.7	2	1
Jt	Thionic Fluvisol	43.0	4.8	4.11	0.209	0.99	17.92	1.07	12.2	5	1
L	Luvisols	22.4	6.4	0.56	0.056	0.46	10.50	1.54	3.9	3	1
La	Albic Luvisol	5.5	6.4	0.28	0.033	0.18	2.92	1.62	1.8	4	1
Lc	Chromic Luvisol	24.9	6.4	0.70	0.094	0.64	12.34	1.53	5.3	3	1

* Erod. = erodibility factor (1 = low; 5 = high); Depth = soil depth class (1 = > 1.0 m; 2 = 0.4-1.0 m; 3 = < 0.4 m)

FAO74	FAO unit	Clay	pH	Org. C	Tot. N	Exch. K	CEC	Bulk	Avail. P	Erod.*	Depth*
		%		%	%	cmol/kg	cmol/kg	kg/dm^3	ppm		
Lf	Ferric Luvisol	21.3	5.9	0.63	0.078	0.40	6.24	1.55	3.0	1	1
Lg	Gleyic Luvisol	29.0	6.1	0.66	0.170	0.60	18.02	1.48	2.9	2	1
Lk	Calcic Luvisol	17.2	8	0.36	0.076	0.68	10.80	1.57	4.9	2	1
Lo	Orthic Luvisol	16.9	6.3	0.46	0.052	0.47	9.42	1.55	4.8	3	1
Lp	Plinthic Luvisol	16.7	5.8	0.58	0.172	0.25	4.24	1.66	2.2	4	2
Lv	Vertic Luvisol	47.6	7	1.26	0.116	2.79	25.56	1.5	21.2	4	2
Mo	Orthic Greyzem	33.7	6.7	1.47	0.180	0.33	15.23	1.5	1.3	2	1
Nd	Dystric Nitosol	10.5	4.9	0.61	0.083	0.13	12.09	1.42	15.0	2	1
Ne	Eutric Nitosol	15.2	6.2	0.53	0.102	0.46	7.15	1.49	2.9	2	1
Nh	Humic Nitosol	16.1	5.2	2.49	0.249	0.41	19.40	1.27	4.3	1	1
Od	Dystric Histosol	4.8	4.5	32.18	1.305	0.47	56.71	0.31	19.6	1	2
Oe	Eutric Histosol	5.1	5.8	40.30	4.000	1.13	86.40	0.33	23.9	1	2
Pg	Gleyic Podzol	16.7	4.7	1.80	0.102	0.13	8.16	1.28	7.9	2	2
Ph	Humic Podzol	3.5	4.2	2.00	0.114	0.06	5.75	1.35	2.8	2	2
Qa	Albic Arenosol	5.7	6.1	0.46	0.042	0.18	3.16	1.59	5.3	4	1
Qc	Cambic Arenosol	6.1	6.6	0.27	0.036	0.30	4.05	1.62	3.4	3	1
Qf	Ferralic Arenosol	5.6	5.6	0.34	0.067	0.15	2.93	1.63	3.1	3	1
Ql	Luvic Arenosol	4.9	6.5	0.23	0.023	0.22	3.32	1.58	2.0	4	1
R	Regosols	18.1	6.3	0.66	0.066	0.45	10.20	1.51	7.8	3	2
Rc	Calcaric Regosol	20.5	8	0.38	0.138	0.54	10.54	1.46	10.3	2	2
Rd	Dystric Regosol	15.3	5.1	1.05	0.095	0.22	7.45	1.51	6.7	3	2
Re	Eutric Regosol	18.6	6.4	0.91	0.121	0.58	14.55	1.56	7.2	3	2
Sg	Gleyic Solonetz	16.2	8	0.38	0.025	0.69	9.47	1.72	2.5	5	2
Sm	Mollic Solonetz	25.5	6.6	0.65	0.080	0.90	13.85	1.68	1.5	3	2
So	Orthic Solonetz	29.8	8.4	0.53	0.058	0.80	18.58	1.63	2.3	5	2
Th	Humic Andosol	19.0	5.5	6.30	0.544	0.52	28.72	0.7	13.3	1	1
Tm	Mollic Andosol	46.3	6.1	3.24	0.406	1.64	25.21	0.73	16.8	1	1
To	Ochric Andosol	56.5	5.8	1.68	0.178	0.80	31.65	0.79	20.4	2	1
Tv	Vitric Andosol	5.3	6.1	7.06	0.735	0.85	38.58	0.8	17.4	2	1
U	Rankers	8.7	5.6	2.32	0.202	0.18	8.15	1.48	2.1	3	3
V	Vertisols	57.4	7.5	0.80	0.080	1.21	45.30	1.67	6.5	4	2
Vc	Chromic Vertisol	55.8	7.9	0.90	0.087	1.37	42.95	1.71	8.2	4	2
Vp	Pellic Vertisol	59.2	7.2	1.16	0.125	1.05	48.61	1.59	3.6	4	2
W	Planosols	12.6	6	0.65	0.065	0.42	8.60	1.57	1.5	4	2
Wd	Dystric Planosol	6.0	4.2	0.20	0.025	0.25	3.00	1.28	1.1	4	2
We	Eutric Planosol	17.7	5.9	0.63	0.059	0.66	8.82	1.51	1.5	4	2
Ws	Solodic Planosol	14.1	6.4	0.50	0.048	0.35	6.69	1.72	1.8	4	2
X	Xerosols	16.7	7.6	0.42	0.042	0.64	10.20	1.49	5.2	4	2
Xh	Haplic Xerosol	10.5	8	0.45	0.052	0.83	7.80	1.52	4.1	4	2
Xk	Calcic Xerosol	22.1	7.9	0.72	0.090	0.45	13.81	1.43	6.1	4	2
Xl	Luvic Xerosol	17.0	7.3	0.32	0.033	0.50	10.71	1.53	6.9	4	2
Xy	Gypsic Xerosol	17.0	7.9	1.32	0.100	0.80	11.10	1.39	5.2	4	2
Y	Yermosols	20.4	7.9	0.25	0.025	0.45	7.50	1.51	7.4	4	2
Yh	Haplic Yermosol	32.5	8.1	0.17	0.030	0.55	24.65	1.54	7.0	4	2
Yk	Calcic Yermosol	12.5	8	0.12	0.027	0.49	8.46	1.49	8.0	4	2
Yl	Luvic Yermosol	16.2	7.5	0.27	0.026	0.31	9.83	1.6	7.8	4	2
Yt	Takyric Yermosol	48.9	7.2	0.21	0.021	1.07	7.50	1.51	7.4	4	2
Yy	Gypsic Yermosol	13.1	7.8	0.18	0.018	0.51	13.00	1.18	7.8	4	2
Z	Solonchaks	24.2	8.2	0.43	0.043	1.70	13.20	1.48	5.2	5	2
Zg	Gleyic Solonchak	28.9	8.3	0.49	0.084	2.03	20.85	1.47	6.9	5	2
Zo	Orthic Solonchak	19.4	8.1	0.28	0.045	1.37	12.71	1.49	3.9	4	2
Zt	Takyric Solonchak	51.0	7.7	0.69	0.090	1.07	27.60	1.48	5.7	4	2

* Erod. = erodibility factor (1 = low; 5 = high); Depth = soil depth class (1 = > 1.0 m; 2 = 0.4-1.0 m; 3 = < 0.4 m)

Annex 7

Data used for macrolevel nutrient balances in a 2003 FAO study on Ghana, Kenya and Mali

IN1: MINERAL FERTILIZER

TABLE A7.1

Fertilizer consumption per crop as factor of total consumption

	Ghana			Kenya			Mali		
Crop	**N**	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**
Banana	0	0	0.02	0.008	0.009	0			
Barley				0.008	0.028	0.011			
Cassava	0.05	0.02	0.03	0	0	0	0	0	0
Citrus	0	0	0	0.003	0.002	0.006			
Cocoa	0	0.01	0.01						
Coconuts	0	0	0	0	0	0			
Coffee	0	0	0	0.116	0.047	0.322			
Cotton	0.03	0.03	0.04	0.002	0.042	0.011	0.53	0.47	0.40
Fallow	0	0	0	0	0	0	0	0	0
Fibres							0	0	0
Groundnuts	0.03	0.07	0.04	0.005	0.004	0	0.04	0.13	0.18
Maize	0.5	0.41	0.42	0.274	0.255	0	0.12	0.20	0.34
Millet	0.05	0.06	0.01	0	0	0	0	0	0
Oil-palm	0.02	0.06	0.07						
Other cereals							0	0	0
Other fruits	0	0	0	0.072	0.043	0.350	0	0	0
Other roots	0.11	0.13	0.1	0	0	0	0	0	0
Plantains	0.01	0.01	0.04	0.005	0.006	0			
Potatoes				0.087	0.064	0			
Pulses	0.01	0.04	0.01	0.106	0.119	0.079	0.00	0.07	0.05
Rice	0.06	0.06	0.09	0.014	0.009	0	0.30	0.12	0.00
Rubber	0	0	0						
Sesame seed				0	0	0			
Sorghum	0.05	0.04	0.04	0.052	0.025	0	0	0	0
Sugar cane	0.01	0.01	0.01	0.026	0.026	0.068	0	0	0
Sunflower Seed				0	0	0			
Sweet potatoes	0	0	0	0	0	0	0	0	0
Tea				0.090	0.023	0.051	0	0	0
Tobacco	0	0	0	0.003	0.011	0.011	0	0	0
Vegetables	0.07	0.05	0.07	0.075	0.125	0.090	0.01	0.01	0.03
Wheat				0.058	0.162	0	0	0	0

TABLE A7.2
Total fertilizer consumption

	N	P	K
		(tonnes)	
Ghana	7 994	2 002	3 920
Kenya	52 733	30 638	11 667
Mali	20 367	6 362	10 694

Source: FAOSTAT.

IN2: ORGANIC INPUTS

TABLE A7.3
Manure application factors per crop*

Crop	Ghana	Kenya	Mali
Banana	0	0	-
Barley	-	1	-
Cassava	0	0	0
Citrus	0	0	-
Cocoa	0	-	-
Coconuts	0	0	-
Coffee	0	2	-
Cotton	1	1	2
Fallow	0	0	0
Fibres	-	-	0
Groundnuts	1	1	1
Maize	1	2	2
Millet	1	1	1
Oil-palm	0	-	-
Other cereals	-	-	1
Other fruits	1	1	1
Other roots	0	0	0
Plantains	0	0	-
Potatoes	-	0	-
Pulses	1	1	0
Rice	0	0	0
Rubber	0	-	-
Sesame seed	-	1	-
Sorghum	1	1	1
Sugar cane	0	0	0
Sunflower Seed	-	0	-
Sweet potatoes	0	0	0
Tea	-	0	0
Tobacco	0	0	0
Vegetables	1	1	1
Wheat	-	1	1

* 0 = no manure, 1 = manure, 2 = twice as much manure.

TABLE A7.4

Aggregation and loss factor for storage of manure

	Ghana	Kenya	Mali
Aggregation factor	2	1.5	2
Loss factor (%)	40	15	25

OUT1: CROP PRODUCTS

TABLE A7.5

Harvested area and yield per country per crop

Crops	Yield (kg/ha)			Harvested area (ha)		
	Ghana	Kenya	Mali	Ghana	Kenya	Mali
Bananas	3 211	5 579	-	4 733	40 333	-
Barley	-	2 581	-	-	22 267	-
Cassava	11 871	9 288	10 071	619 760	98 333	907
Citrus	7 073	6 886	-	41 867	6 521	-
Cocoa	302	-	-	1 246 500	-	-
Coconuts	5 714	4 402	-	53 100	15 000	-
Coffee	323	362	-	15 710	178 136	-
Cotton	820	595	1 011	50 387	38 866	496 401
Fibres	-	-	650	-	-	2 000
Groundnuts	1 007	1 276	854	185 077	15 145	190 248
Maize	1 489	1 513	1 564	681 707	1 523 587	286 232
Millet	885	504	823	178 910	88 233	920 416
Oil-palm	9 404	-	-	106 667	-	-
Other cereals	-	-	333	-	-	300
Other fruits	7 536	6 653	13 950	19 800	23 482	3 197
Other roots	8 964	5 000	5 878	213 787	2 000	4 402
Plantains	7 956	4 492	-	241 233	85 333	-
Potatoes	-	4 347	-	-	94 051	-
Pulses	100	350	371	153 333	700 000	319 715
Rice	1 699	3 749	2 030	117 800	14 607	328 494
Rubber	611	-	-	17 133	-	-
Sesame seed	-	429	-	-	28 000	-
Sorghum	1 056	915	970	322 553	136 667	634 920
Sugar cane	25 369	83 621	67 970	5 600	58 000	4 477
Sunflower seed	-	850	-	-	9 432	-
Sweet potatoes	1 369	9 579	7 024	6 0200	71 333	3 730
Tea	-	2 214	630	-	114 964	90
Tobacco	591	1 185	987	3 900	13 980	376
Vegetables	5 255	8 289	6 623	131 688	81 523	48 564
Wheat	-	1 570	1 818	-	144 405	3 104

Source: FAOSTAT.

OUT2: CROP RESIDUES

TABLE A7.6
Crop residue removal factors per country

Crop	Ghana	Kenya (%)	Mali
Banana	10	20	-
Barley	-	35	-
Cassava	40	20	20
Citrus	10	15	-
Cocoa	10	-	-
Coconuts	10	20	-
Coffee	10	15	-
Cotton*	60	60	60
Fallow	5	5	5
Fibres	-	-	10
Groundnuts	30	60	80
Maize	30	75	80
Millet	30	70	50
Oil-palm	10	-	-
Other cereals	-	-	60
Other fruits	40	50	50
Other roots	25	20	25
Plantains	10	20	-
Potatoes	-	20	-
Pulses	30	70	80
Rice	15	20	35
Rubber	10	-	-
Sesame seed	-	75	-
Sorghum	30	70	50
Sugar cane	10	20	20
Sunflower seed	-	40	-
Sweet potatoes	30	20	30
Tea	-	15	10
Tobacco	10	20	10
Vegetables	40	60	80
Wheat	-	60	40

* Cotton is mainly removed by burning, which means all N and 50 percent of K is lost.

Annex 8

Results of the macrolevel nutrient-balance calculations from a 2003 FAO study of Ghana, Kenya and Mali

TABLE A8.1

Nitrogen flows for Ghana

Crops	Area	IN1	IN2	IN3	IN4	IN5	OUT1	OUT2	OUT3	OUT4	OUT5
	(ha)	(kg/ha)									
Cocoa	1 242 300	0.0	0.1	8.7	4.6	0.0	12.1	0.6	4.3	1.6	10.7
Fallow	824 900	0.0	0.2	7.0	4.1	0.0	0.0	0.2	11.7	1.3	7.4
Maize	679 900	5.9	0.6	6.7	4.1	0.0	25.0	4.3	6.2	2.0	0.9
Cassava	618 100	0.6	0.2	6.8	4.1	0.0	49.9	21.8	1.8	1.4	4.6
Sorghum	323 700	1.2	0.5	6.7	4.1	0.0	15.3	3.4	6.9	1.4	2.9
Plantains	240 100	0.3	0.1	8.9	4.7	0.0	5.6	1.0	9.5	1.7	6.9
Other roots	214 500	4.1	0.2	7.2	4.2	0.0	41.2	4.3	0.8	1.8	-0.5
Groundnuts	184 800	1.3	0.5	6.8	38.8	0.0	37.5	4.8	1.6	1.4	3.8
Millet	177 900	2.2	0.6	6.7	4.0	0.0	17.0	5.4	6.8	1.5	4.4
Pulses	155 100	0.5	0.4	8.1	6.1	0.0	2.0	0.3	17.8	1.6	10.3
Vegetables	131 700	4.2	0.3	8.7	4.6	0.0	47.3	6.7	0.7	2.2	12.0
Rice	118 300	4.1	0.1	8.8	6.9	0.0	19.7	2.9	16.1	2.1	14.3
Oil-palm	107 000	1.5	0.1	8.8	4.6	0.0	27.3	3.5	0.0	1.8	16.2
Sweet potato	60 200	0.0	0.1	6.9	4.1	0.0	6.6	0.9	9.6	1.3	-1.4
Coconuts	52 100	0.0	0.1	8.8	4.7	0.0	349	15.4	0.0	1.6	16.3
Cotton	50 400	4.8	0.3	7.2	4.2	0.0	15.3	9.1	9.2	2.0	5.0
Citrus	42 500	0.0	0.1	7.4	4.3	0.0	12.7	0.4	2.0	1.3	9.3
Other fruits	19 900	0.0	0.2	8.5	4.6	0.0	15.1	5.4	1.7	1.6	16.5
Rubber	18 000	0.0	0.0	10.5	5.1	0.0	4.2	0.1	5.1	1.9	1.9
Coffee	15 200	0.0	0.0	10.7	5.1	0.0	11.3	0.1	2.0	2.0	10.5
Sugar cane	5 600	14.3	0.1	8.4	8.4	0.0	15.2	0.8	6.3	3.4	8.2
Bananas	4 600	0.0	0.1	9.0	4.7	0.0	3.9	0.5	14.3	1.6	34.6
Tobacco	2 300	0.0	0.2	4.8	3.5	0.0	33.1	0.0	2.5	0.9	0.3

TABLE A8.2

Phosphorus flows for Ghana

Crops	Area	IN1	IN2	IN3	IN5	OUT1	OUT2	OUT5
	(ha)	(kg/ha)						
Cocoa	1 242 300	0.0	0.0	1.2	0.0	2.6	0.1	1.0
Fallow	824 900	0.0	0.1	0.9	0.0	0.0	0.1	0.5
Maize	679 900	1.2	0.1	0.9	0.0	6.1	0.9	0.2
Cassava	618 100	0.1	0.0	0.9	0.0	5.7	4.3	0.0
Sorghum	323 700	0.2	0.1	0.9	0.0	5.8	1.4	0.1
Plantains	240 100	0.1	0.0	1.2	0.0	0.7	0.2	0.8
Other roots	214 500	1.2	0.1	1.0	0.0	2.7	1.1	0.1
Groundnuts	184 800	0.8	0.1	0.9	0.0	6.0	0.7	0.2
Millet	177 900	0.7	0.1	0.9	0.0	5.3	1.1	0.6
Pulses	155 100	0.5	0.1	1.1	0.0	0.3	0.0	1.2
Vegetables	131 700	0.8	0.1	1.2	0.0	4.8	2.9	1.3
Rice	118 300	1.0	0.0	1.2	0.0	5.8	0.6	1.7
Oil-palm	107 000	1.1	0.0	1.2	0.0	6.5	0.5	1.6
Sweet Potatoes	60 200	0.0	0.0	0.9	0.0	1.1	0.5	-0.1
Coconuts	52 100	0.0	0.0	1.2	0.0	41	3.3	1.8
Cotton	50 400	1.2	0.1	1.0	0.0	7.9	0.0	0.6
Citrus	42 500	0.0	0.0	1.0	0.0	1.5	0.2	0.9
Other fruits	19 900	0.0	0.1	1.1	0.0	1.6	0.7	1.8
Rubber	18 000	0.0	0.0	1.4	0.0	0.7	0.0	0.4
Coffee	15 200	0.0	0.0	1.4	0.0	0.8	0.1	1.4
Sugar cane	5 600	3.6	0.0	1.1	0.0	5.5	0.8	0.7
Bananas	4 600	0.0	0.0	1.2	0.0	1.0	0.1	3.3
Tobacco	2 300	0.0	0.1	0.7	0.0	4.8	0.0	0.1

TABLE A8.3

Potassium flows for Ghana

Crops	Area	IN1	IN2	IN3	IN5	OUT1	OUT2	OUT3	OUT5
	(ha)	(kg/ha)							
Cocoa	1 242 300	0.0	0.0	6.6	0.0	5.8	1.0	11.6	1.1
Fallow	824 900	0.0	0.2	6.1	0.0	0.0	0.2	6.6	0.9
Maize	679 900	2.4	0.4	6.1	0.0	7.1	9.6	7.3	0.2
Cassava	618 100	0.2	0.1	5.7	0.0	50.5	6.7	6.1	0.1
Sorghum	323 700	0.5	0.4	6.0	0.0	4.0	9.2	6.4	0.5
Plantains	240 100	0.6	0.0	6.6	0.0	27.2	5.1	12.1	0.6
Other roots	214 500	1.8	0.1	5.9	0.0	26.1	6.9	8.4	-0.5
Groundnuts	184 800	0.8	0.4	6.1	0.0	8.2	4.5	6.6	0.6
Millet	177 900	0.2	0.5	6.0	0.0	4.8	15.9	6.5	1.3
Pulses	155 100	0.3	0.3	6.4	0.0	1.1	0.4	10.0	0.8
Vegetables	131 700	2.1	0.2	6.5	0.0	13.6	16.5	12.2	1.3
Rice	118 300	3.0	0.0	6.6	0.0	5.8	9.1	12.4	1.3
Oil-palm	107 000	2.6	0.0	6.5	0.0	38.4	3.1	12.0	1.9
Sweet potatoes	60 200	0.0	0.1	5.8	0.0	10.0	1.3	6.9	-0.5
Coconuts	52 100	0.0	0.0	6.6	0.0	56.2	14.5	11.9	1.7
Cotton	50 400	3.1	0.2	6.0	0.0	7.4	9.8	8.5	0.5
Citrus	42 500	0.0	0.1	6.0	0.0	16.5	3.1	8.1	1.7
Other fruits	19 900	0.0	0.1	6.4	0.0	15.1	14.8	11.0	1.8
Rubber	18 000	0.0	0.0	7.2	0.0	2.8	0.2	16.0	0.0
Coffee	15 200	0.0	0.0	7.3	0.0	5.4	0.3	16.6	0.8
Sugar cane	5 600	7.0	0.0	6.3	0.0	29.6	0.8	13.2	0.8
Bananas	4 600	16.6	0.0	6.6	0.0	14.5	3.8	12.1	4.5
Tobacco	2 300	0.0	0.2	4.5	0.0	42.9	0.0	0.5	0.2

TABLE A8.4

Nitrogen flows for Kenya

Crops	Area	IN1	IN2	IN3	IN4	IN5	OUT1	OUT2	OUT3	OUT4	OUT5
	(ha)	(kg/ha)									
Maize	1 524 700	9.5	5.4	3.7	3.2	0.0	25.4	11.0	6.7	2.7	24.4
Fallow	914 800	0.0	1.7	4.0	3.3	0.0	0.0	1.7	11.2	1.1	25.3
Pulses	699 800	8.0	1.7	3.2	8.9	0.0	7.0	2.5	12.2	1.9	9.6
Coffee	179 200	34.2	10.6	6.6	4.1	0.1	12.7	0.2	20.8	7.2	37.0
Wheat	144 500	21.1	2.9	3.8	3.3	0.0	35.0	4.0	5.9	3.9	13.3
Sorghum	136 600	20.0	2.3	3.3	3.1	0.0	13.3	6.9	7.0	3.7	10.7
Tea	114 900	41.2	3.5	7.3	4.4	0.0	77.5	0.0	2.3	7.3	67.0
Cassava	98 600	0.0	2.8	6.3	4.1	0.0	39.0	8.5	13.1	1.7	52.5
Potatoes	94 100	48.6	0.7	3.1	3.0	0.0	19.1	2.0	24.4	7.1	35.4
Millet	90 100	0.0	1.4	2.7	2.9	0.0	9.7	7.2	4.8	0.8	1.5
Plantains	84 200	2.8	3.6	7.1	4.3	0.0	3.1	1.1	31.5	2.3	49.9
Vegetables	81 500	48.2	5.7	5.7	3.9	0.0	74.6	15.9	19.8	8.1	-3.1
Sweet potatoes	71 900	0.0	1.2	4.0	3.4	0.0	46.0	4.0	0.3	1.0	21.0
Sugar cane	60 000	23.5	2.2	8.1	17.4	0.0	50.2	5.0	2.2	4.9	23.5
Bananas	40 200	9.9	2.8	6.2	4.1	0.0	6.7	1.8	30.4	3.0	6.2
Cotton	38 900	2.1	3.4	4.1	3.4	0.0	11.1	6.6	6.1	1.6	53.8
Sesame seed	26 400	0.0	1.6	2.9	3.0	0.0	12.9	4.8	4.3	0.8	-9.5
Other fruits	25 200	161	6.6	6.8	4.2	0.0	13.3	6.0	69.9	23.2	64.7
Barley	22 100	18.0	1.4	2.7	2.9	0.0	40.0	6.3	2.8	3.1	-0.4
Groundnuts	16 500	15.9	3.2	3.6	47.2	0.0	47.5	12.2	4.8	3.2	7.7
Tobacco	14 100	11.5	1.4	3.1	3.0	0.0	66.3	0.0	0.0	2.3	0.2
Rice	13 600	49.4	1.3	8.1	8.3	0.0	43.5	8.5	25.6	8.1	28.9
Coconuts	13 500	0.0	3.5	6.7	4.2	0.0	268.5	23.8	0.0	1.9	163.4
Sunflower seed	10 700	0.0	1.1	3.5	3.2	0.0	20.4	7.8	8.3	0.8	16.2
Citrus	5 200	28.3	2.2	6.6	4.2	0.0	12.4	0.6	17.3	5.3	13.3
Other roots	1 800	0.0	0.5	5.1	3.7	0.0	23.0	1.9	5.3	1.1	-0.1

TABLE A8.5

Phosphorus flows for Kenya

Crops	Area (ha)	IN1	IN2	IN3	IN5	OUT1	OUT2	OUT5
		(kg/ha)						
Maize	1 524 700	5.1	1.1	0.5	0.0	6.2	2.2	3.4
Fallow	914 800	0.0	0.4	0.5	0.0	0.0	0.4	2.4
Pulses	699 800	5.2	0.4	0.4	0.0	1.2	0.2	1.3
Coffee	179 200	8.1	2.2	0.8	0.0	0.9	0.2	2.7
Wheat	144 500	34.4	0.6	0.5	0.0	6.8	1.7	1.7
Sorghum	136 600	5.5	0.5	0.4	0.0	5.0	2.9	1.8
Tea	114 900	6.0	0.7	0.9	0.0	8.4	0.0	5.9
Cassava	98 600	0.0	0.6	0.8	0.0	4.4	1.7	2.6
Potatoes	94 100	20.9	0.1	0.4	0.0	5.7	0.6	4.5
Millet	90 100	0.0	0.3	0.3	0.0	3.0	1.4	0.2
Plantains	84 200	2.0	0.8	0.9	0.0	0.4	0.3	2.3
Vegetables	81 500	46.8	1.2	0.7	0.0	7.6	6.9	-0.1
Sweet potatoes	71 900	0.0	0.3	0.5	0.0	7.5	2.2	1.4
Sugar cane	60 000	14.0	0.4	1.0	0.0	18.2	5.1	2.7
Bananas	40 200	7.2	0.6	0.8	0.0	1.7	0.3	-1.3
Cotton	38 900	32.7	0.7	0.5	0.0	5.7	0.0	5.8
Sesame seed	26 400	0.0	0.3	0.4	0.0	2.6	1.7	-0.7
Other fruits	25 200	56.6	1.4	0.9	0.0	1.4	0.7	3.2
Barley	22 100	38.9	0.3	0.4	0.0	7.2	0.9	-0.1
Groundnuts	16 500	7.6	0.7	0.5	0.0	7.6	1.8	0.9
Tobacco	14 100	24.8	0.3	0.4	0.0	9.7	0.0	0.0
Rice	13 600	19.8	0.3	1.0	0.0	12.7	1.7	2.9
Coconuts	13 500	0.0	0.7	0.9	0.0	31.6	5.0	7.1
Sunflower seed	10 700	0.0	0.2	0.4	0.0	3.0	1.1	1.6
Citrus	5 200	8.9	0.5	0.9	0.0	1.5	0.2	0.7
Other roots	1 800	0.0	0.1	0.7	0.0	1.5	0.5	0.0

TABLE A8.6

Potassium flows for Kenya

Crops	Area	IN1	IN2	IN3	IN5	OUT1	OUT2	OUT3	OUT5
	(ha)				(kg/ha)				
Maize	1 524 700	0.0	4.5	2.0	0.0	7.2	24.3	2.3	7.9
Fallow	914 800	0.0	1.4	2.2	0.0	0.0	1.4	1.3	4.6
Pulses	699 800	1.3	1.4	1.7	0.0	3.9	3.2	1.0	2.8
Coffee	179 200	21.1	8.8	3.5	0.0	6.1	0.5	12.7	7.5
Wheat	144 500	0.0	2.4	2.1	0.0	9.2	25.1	4.7	3.8
Sorghum	136 600	0.0	1.9	1.8	0.0	3.4	18.7	2.2	1.6
Tea	114 900	5.2	2.8	3.9	0.0	29.7	0.0	14.7	7.6
Cassava	98 600	0.0	2.3	3.4	0.0	39.5	2.6	5.0	4.2
Potatoes	94 100	0.0	0.6	1.7	0.0	30.1	3.9	6.8	7.2
Millet	90 100	0.0	1.2	1.5	0.0	2.7	21.1	0.0	0.3
Plantains	84 200	0.0	2.9	3.8	0.0	15.3	5.8	6.4	5.7
Vegetables	81 500	12.9	4.9	3.1	0.0	21.4	39.0	14.0	-0.5
Sweet potatoes	71 900	0.0	1.0	2.1	0.0	70.2	6.2	1.1	4.1
Sugar cane	60 000	13.6	1.8	4.3	0.0	97.6	5.6	12.2	8.0
Bananas	40 200	0.0	2.3	3.4	0.0	25.1	13.3	6.1	-2.9
Cotton	38 900	3.4	2.8	2.2	0.0	5.4	7.1	1.8	10.1
Sesame seed	26 400	0.0	1.4	1.6	0.0	2.9	6.8	0.1	-2.0
Other fruits	25 200	174	5.3	3.7	0.0	13.3	16.4	33.6	6.0
Barley	22 100	5.9	1.1	1.5	0.0	15.5	19.0	0.8	-0.1
Groundnuts	16 500	0.0	2.7	1.9	0.0	10.4	11.4	2.7	2.1
Tobacco	14 100	9.4	1.2	1.7	0.0	86.1	0.0	1.5	0.0
Rice	13 600	0.0	1.1	4.3	0.0	12.8	26.8	16.7	9.5
Coconuts	13 500	0.0	2.8	3.6	0.0	43.3	22.3	4.7	11.4
Sunflower seed	10 700	0.0	0.9	1.9	0.0	4.7	14.0	1.0	1.5
Citrus	5 200	10.1	1.9	3.6	0.0	16.1	4.6	10.7	1.4
Other roots	1 800	0.0	0.4	2.8	0.0	14.6	3.1	3.4	0.0

TABLE A8.7

Nitrogen flows for Mali

Crops	Area	IN1	IN2	IN3	IN4	IN5	OUT1	OUT2	OUT3	OUT4	OUT5
	(ha)					(kg/ha)					
Fallow	1 402 800	0.0	0.6	4.2	3.4	0.1	0.0	0.6	7.6	0.9	0.3
Millet	921 000	0.0	0.9	3.9	3.3	0.0	15.8	8.4	5.1	0.9	0.4
Sorghum	633 400	0.0	1.2	5.2	3.7	0.0	14.1	5.2	7.5	1.2	1.2
Cotton	493 800	21.7	1.7	4.9	3.7	0.0	18.9	8.4	10.6	4.0	0.8
Rice	328 800	18.6	1.2	2.7	17.1	0.4	23.5	8.0	9.8	3.2	0.8
Pulses	316 200	0.0	0.4	5.1	9.9	0.0	7.4	3.1	12.8	1.0	-0.3
Maize	284 600	8.5	1.2	4.2	3.4	0.0	26.3	12.1	6.1	2.1	0.4
Groundnuts	191 700	4.3	1.0	4.7	33.1	0.0	31.8	10.9	6.5	1.6	0.3
Vegetables	46 800	4.2	1.2	6.6	4.1	0.0	59.6	17.0	1.9	2.0	-6.9
Sugar cane	6 800	0.0	0.5	7.5	14.8	0.0	40.8	4.1	0.0	1.5	0.4
Cassava	5 500	0.0	0.5	7.2	4.3	0.0	42.3	9.3	0.0	1.4	3.7
Other fruits	4 700	0.0	0.9	7.4	4.4	0.0	27.9	12.6	0.0	1.5	-14.7
Sweet potatoes	4 000	0.0	0.3	4.2	3.4	0.0	33.7	4.4	2.5	0.9	0.3
Tobacco	2 300	0.0	0.4	4.7	3.6	0.0	55.3	0.0	0.0	1.0	0.1
Wheat	2 300	0.0	0.9	3.9	3.3	0.0	40.5	3.1	0.0	0.9	0.3
Fibres	1 900	0.0	0.2	3.8	3.3	0.0	3.3	0.1	7.7	0.8	0.3

TABLE A8.8

Phosphorus flows for Mali

Crops	Area	IN1	IN2	IN3	IN5	OUT1	OUT2	OUT5
	(ha)	(kg/ha)						
Fallow	1 402 800	0.0	0.1	0.5	0.0	0.0	0.1	0.0
Millet	921 000	0.0	0.2	0.5	0.0	4.9	1.6	0.1
Sorghum	633 400	0.0	0.3	0.7	0.0	5.3	2.2	0.2
Cotton	493 800	6.0	0.4	0.6	0.0	9.8	0.0	0.2
Rice	328 800	2.3	0.3	0.3	0.0	6.9	1.6	0.1
Pulses	316 200	1.4	0.1	0.7	0.0	1.3	0.3	0.0
Maize	284 600	4.4	0.3	0.5	0.0	6.4	2.4	0.1
Groundnuts	191 700	4.3	0.2	0.6	0.0	5.1	1.6	0.1
Vegetables	46 800	1.3	0.3	0.9	0.0	6.0	7.4	0.0
Sugar cane	6 800	0.0	0.1	1.0	0.0	14.8	4.1	0.0
Cassava	5 500	0.0	0.1	0.9	0.0	4.8	1.8	0.9
Other fruits	4 700	0.0	0.2	1.0	0.0	3.0	1.5	-0.9
Sweet potatoes	4 000	0.0	0.1	0.5	0.0	5.5	2.5	0.0
Tobacco	2 300	0.0	0.1	0.6	0.0	8.1	0.0	0.0
Wheat	2 300	0.0	0.2	0.5	0.0	7.8	1.3	0.0
Fibres	1 900	0.0	0.0	0.5	0.0	0.3	0.0	0.0

TABLE A8.9

Potassium flows for Mali

Crops	Area	IN1	IN2	IN3	IN5	OUT1	OUT2	OUT3	OUT5
	(ha)	(kg/ha)							
Fallow	1 402 800	0.0	0.4	2.3	0.0	0.0	0.4	1.8	0.1
Millet	921 000	0.0	0.7	2.1	0.0	4.5	24.6	0.9	0.1
Sorghum	633 400	0.0	1.0	2.8	0.0	3.6	14.1	3.7	0.2
Cotton	493 800	8.6	1.4	2.6	0.0	9.1	9.0	6.7	0.2
Rice	328 800	0.0	1.0	1.4	0.2	6.9	25.4	0.7	0.2
Pulses	316 200	1.7	0.3	2.7	0.0	4.1	3.9	3.7	-0.1
Maize	284 600	12.7	0.9	2.3	0.0	7.4	26.8	2.8	0.1
Groundnuts	191 700	10.1	0.8	2.6	0.0	7.0	10.2	3.4	0.1
Vegetables	46 800	6.6	1.0	3.5	0.0	17.1	41.5	8.5	-1.3
Sugar cane	6 800	0.0	0.4	4.1	0.0	79.3	4.5	9.6	0.0
Cassava	5 500	0.0	0.4	3.9	0.0	42.8	2.9	8.2	0.6
Other fruits	4 700	0.0	0.8	4.0	0.0	27.9	34.3	9.2	-2.7
Sweet potatoes	4 000	0.0	0.2	2.2	0.0	51.5	6.8	1.0	0.1
Tobacco	2 300	0.0	0.3	2.5	0.0	71.7	0.0	2.7	0.0
Wheat	2 300	0.0	0.7	2.1	0.0	10.6	19.4	1.0	0.1
Fibres	1 900	0.0	0.1	2.1	0.0	3.9	0.6	0.7	0.1

Annex 9

Data used for mesolevel nutrient balances from a 2003 FAO study of Ghana, Kenya and Mali

GHANA

TABLE A9.1
Production data for Nkawie District

Crops	Harvested area (ha)	Yield (tonnes/ha)	Production (tonnes)	Residue removal (%)
Cassava	11 838	11.6	137 317	40
Cocoa	48 493	0.22	10 652	50
Cocoyam	9 514	10.25	97 475	25
Fallow	14 600	0	0	0*
Maize	11 455	1.75	19 953	30
Plantain	11 725	8.2	96 106	10
Rice	1 462	1.54	2 245	15
Yam	1 175	11.6	12 992	25

* No removal factor, fallow assumed untouched.

TABLE A9.2
Production data for Wassa Amenfi District

Crop	Harvested area (ha)	Yield (tonnes/ha)	Production (tonnes)	Residue removal (%)
Cassava	7 700	10	70 000	30
Cocoa	240 961	0.22	53 045	50
Cocoyam	3 000	7	21 000	15
Fallow	7 300	0	0	0*
Maize	5 650	1.5	8 475	15
Oil-palm	900	12	10 800	10
Plantain	5 000	8	40 000	10
Rice	2 112	1.3	2 746	10
Vegetables	250	6	1 500	30
Yam	1 500	18	27 000	15

* No removal factor, fallow assumed untouched.

TABLE A9.3
Number of livestock, both districts

Animal	Nkawie	Wassa Amenfi	Body weight (kg)
Cattle		156	175
Goat	2 114	2 623	16
Poultry	528 608	4 565	2
Sheep	3 176	11 480	16

TABLE A9.4

Nutrient content data

Product	N	P	K	Unit
Cocoa leaf litter	1.19	0.08	0.22	% of oven dry weight
Pod husk	1.14	0.13	3.32	% of oven dry husk
Cocoa bean	20.70	3.60	6.70	kg/tonne harvested product
Cocoa testa	2.02	0.32	1.70	kg/tonne harvested product

KENYA

TABLE A9.5

Production data for the tea-coffee-dairy zone of Embu District

Crop	Harvested area (ha)	Yield (tonnes/ha)	Production (tonnes)	Residue removal (%)
Arrow roots	260	3.4	894	20
Beans	2 748	0.5	1 240	97
Cassava	515	10.3	5 280	20
Coffee	8 813	1.5	12 800	15
Cowpeas	280	1.5	410	97
Fallow	1 800	0	18 000*	5
Maize	5 143	2.0	10 452	95
Napier	602	35.0	21 076	-
Potatoes	678	6.1	4 130	20
Sorghum	207	0.9	189	85
Sweet potatoes	140	9.6	1 341	95
Tea	1 092	8.8	9 600	15

* Estimate based on a ‘yield’ of 10 tonnes/ha and a removal factor of 5% (fuelwood and fodder).

TABLE A9.6

Number of livestock in the study area

Animal	Population	Body weight (kg)
Cattle, beef	3 258	300
Cattle, dairy	19 930	300
Chickens	14 261	2
Goats, dairy	227	16
Goats, meat	12 483	16
Sheep, hair	4 991	16
Sheep, wool	77	16

TABLE A9.7

Manure application data for the tea-coffee-dairy zone

Crop	Harvested area	Factor total manure	N	P	K
	(ha)	(%)	(kg/ha)	(kg/ha)	(kg/ha)
Beans	2 748	2	0.9	0.2	0.8
Coffee	8 813	36	5.3	1.1	4.6
Fallow	1 800	4.5	3.2	0.6	2.8
Maize	5 143	51	12.8	2.6	11.1
Napier	602	5	10.7	2.2	9.3
Sorghum	1 197	1	6.2	1.3	5.4
Sweet potatoes	140	0.5	4.6	0.9	4.0

MALI

TABLE A9.8

Number of farms and cultivated area

	1997	1998	1999	Average*
Number of farms	41 031	42 262	43 530	42 274
Cultivated area per farm (ha)	10.75	11.49	11.35	11.20

* Total cultivated area is 4 733 km^2, which is 25.5 percent of the total area.
Source: CMDT/SE (1998-2000).

TABLE A9.9

Harvested areas

Crop	1997		1998		1999		Average		Total
	ha	% farms	ha	% farms	ha	% farms	ha	% farms	ha
Cotton	3.94	90	4.33	89	3.4	85	3.9	88.0	3.42
Cowpea	0.49	28	0.57	22	0.54	25	0.5	25.0	0.13
Groundnut	0.55	57	0.49	56	0.62	59	0.6	57.3	0.32
Maize	1.17	93	1.59	96	1.56	92	1.4	93.7	1.35
Millet	3.13	73	2.63	69	3.74	85	3.2	75.7	2.40
Rice	0.6	12	1.19	20	0.68	16	0.8	16.0	0.13
Sorghum	3.08	95	3.63	96	3.02	94	3.2	95.0	3.08

Source: CMDT/SE (1998-2000).

TABLE A9.10

Yield in kg/ha

Crop	1997	1998	1999	Average
Cotton	948	961	985	965
Cowpea	547	292	524	454
Groundnut	582	503	607	564
Maize	1 746	1 743	1 678	1 722
Millet	759	885	932	859
Rice	1 439	1 424	827	1 230
Sorghum	974	882	1 107	988

Source: CMDT/SE (1998-2000).

TABLE A9.11
Fertilizer application data

Crops	Fertilizer *	1997		1998		1999		Average	
		% fields	(kg/ha)	% fields	(kg/ha)	% fields	(kg/ha)	% fields	(kg/ha)
Cotton	1	98	48	97	46	?	49	97.5	48
	2	99	113	100	119	?	125	99.5	119
	3	1	58	0	0	0	0	0.3	19
Maize	1	70	65	72	61	65	56	69	61
	2	26	68	15	60	14	89	18	72
	3	45	79	55	74	53	83	51	79
Millet	1	21	36	17	48	23	36	20	40
	2	0	0	0	0	2	49	1	16
	3	19	51	9	60	31	54	20	55
Rice	1	4	46	18	33	35	68	19	49
	3	7	110	6	56	17	73	10	80
Sorghum	1	8	45	11	39	15	43	11	42
	2	1	19	1	47	3	47	2	38
	3	16	35	10	65	20	62	15	54

* 1 = urea, 2 = Cotton complex and 3 = Cereal complex
Source: CMDT/SE (1998-2000).

TABLE A9.12
Number of animals per farm and total

Animal	1997	1998	1999	Average	Total	Body weight (kg)
Asses	1.0	1.0	1.0	1.0	42 274	
Cattle	12.1	13.8	12.3	12.7	538 289	200
Goats	4.6	5.8	4.3	4.9	207 143	20
Pigs	0.7	0.3	0.7	0.6	23 955	
Poultry	21.6	23.3	21.0	22.0	928 619	1
Sheep	5.4	6.2	5.7	5.8	243 780	20

Source: CMDT/SE (1998-2000).

TABLE A9.13
Manure application data for Koutiala Region

Crop	1997		1998		1999		Average	
	(kg/ha)	(%)	(kg/ha)	(%)	(kg/ha)	(%)	(kg/ha)	(%)
Cotton	3 463	86.0	4 031	76.0	5 078	72.0	4 191	78.0
Maize	5 765	9.5	5 812	9.5	6 241	28.0	5 939	15.7
Millet	1 869	2.4	2 273	2.4	1 451	2.4	1 864	2.4
Rice	0	0	1 714	2	0	0	571	0.8
Sorghum	607	2.4	1 636	0.0	0	0.0	748	0.8

Source: SEP (1997-99).

Annex 10

Results of the mesolevel nutrient balance calculations from a 2003 FAO study of Ghana, Kenya and Mali

GHANA, NKAWIE DISTRICT

Cassava

Harvested area: 11 838 ha 137 317 tonnes production

	N	P	K	
		(kg/ha)		
IN1	0.64	0.06	0.19	(macrolevel)
IN2	0.59	0.21	0.20	((available manure * loss * factor) / harvested area)
IN3	7.36	0.98	5.91	(macrolevel)
IN4	4.26	0.00	0.00	(only non-symbiotic)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	48.72	5.57	49.30	(production * nut content)
OUT2	21.34	4.22	6.59	(production * residue removal * nut content)
OUT3	0.00	0.00	8.39	(leaching formula, root depth = 0.6)
OUT4	1.50	0.00	0.00	(regression model)
OUT5	9.60	1.09	1.00	(5 tonnes/ha erosion)
Total	-68.3	-9.6	-59.0	

Cocoa

Harvested area: 48 493 ha 10 652 tonnes production

	N	P	K	
		(kg/ha)		
IN1	0.00	0.06	0.08	(63 ha fertilized with kg P and kg K)
IN2	0.00	0.00	0.00	(no organic inputs)
IN3	7.36	0.98	5.91	(macrolevel)
IN4	4.26	0.00	0.00	(only non-symbiotic)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	4.55	0.79	1.47	(production * nut content)
OUT2	1.52	0.17	4.44	(50% of husk lost, put on one heap or used for soap)
OUT3	5.52	0.00	8.34	(leaching formula, root depth = 0.7)
OUT4	1.34	0.00	0.00	(regression model)
OUT5	1.92	0.22	0.20	(1 tonne/ha erosion)
Total	-3.2	-0.1	-8.5	

Cocoyam

Harvested area: 9 514 ha 97 475 tonnes production

	N	P	K	
		(kg/ha)		
IN1	4.11	1.22	1.83	(macrolevel)
IN2	0.89	0.31	0.30	((available manure * loss * factor) / harvested area)
IN3	7.36	0.98	5.91	(macrolevel)
IN4	4.26	0.00	0.00	(only non-symbiotic)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	47.13	3.07	29.92	(production * nut content)
OUT2	4.87	1.23	7.89	(production * residue removal * nut content)
OUT3	0.00	0.00	8.70	(leaching formula, root depth = 0.5)
OUT4	1.97	0.00	0.00	(regression model)
OUT5	13.44	1.53	1.40	(7 tonnes/ha erosion)
Total	-50.8	-3.3	-39.9	

Fallow

Harvested area: 14 600 ha 0 tonnes production

	N	P	K	
		(kg/ha)		
IN1	0.00	0.00	0.00	(no mineral fertilizer)
IN2	0.00	0.00	0.00	(input of manure is equal to removal of crop residues)
IN3	7.36	0.98	5.91	(macrolevel)
IN4	4.26	0.00	0.00	(only non-symbiotic)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	0.00	0.00	0.00	(no crop products)
OUT2	0.00	0.00	0.00	(removal of crop residues is equal to input of manure)
OUT3	9.93	0.00	8.33	(leaching formula, root depth = 0.5)
OUT4	1.34	0.00	0.00	(regression model)
OUT5	0.96	0.11	0.10	(0.5 tonnes/ha erosion)
Total	-0.6	0.9	-2.5	

Maize

Harvested area: 11 455 ha 19 953 tonnes production

	N	P	K	
		(kg/ha)		
IN1	5.86	1.20	2.42	(macrolevel)
IN2	2.05	0.72	0.69	((available manure * loss * factor) / harvested area)
IN3	7.36	0.98	5.91	(macrolevel)
IN4	4.26	0.00	0.00	(only non-symbiotic)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	29.26	7.12	8.27	(production * nut content)
OUT2	5.07	1.00	11.19	(production * residue removal * nut content)
OUT3	5.61	0.00	8.86	(leaching formula, root depth = 0.9)
OUT4	2.34	0.00	0.00	(regression model)
OUT5	9.60	1.09	1.00	(5 tonnes/ha erosion)
Total	-32.4	-6.3	-20.3	

Plantain

Harvested area: 11 725 ha 96 106 tonnes production

	N	P	K	
		(kg/ha)		
IN1	0.33	0.08	0.65	(macrolevel)
IN2	0.60	0.21	0.20	((available manure * loss * factor) / harvested area)
IN3	7.36	0.98	5.91	(macrolevel)
IN4	4.26	0.00	0.00	(only non-symbiotic)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	5.74	0.71	28.03	(production * nut content)
OUT2	0.98	0.25	5.26	(production * residue removal * nut content)
OUT3	7.34	0.00	8.47	(leaching formula, root depth = 0.5)
OUT4	1.46	0.00	0.00	(regression model)
OUT5	5.76	0.66	0.60	(3 tonnes/ha erosion)
Total	-8.7	-0.3	-35.6	

Rice

Harvested area: 1 462 ha 2 245 tonnes production

	N	P	K	
		(kg/ha)		
IN1	4.07	1.02	3.00	(macrolevel)
IN2	0.00	0.00	0.00	((available manure * loss * factor) / harvested area)
IN3	7.36	0.98	5.91	(macrolevel)
IN4	4.26	0.00	0.00	(only non-symbiotic)
IN5	26.49	7.73	3.68	(sedimentation of 1 mm/year, including enrichment factor)
OUT1	17.81	5.21	5.25	(production * nut content)
OUT2	2.60	0.53	8.23	(production * residue removal * nut content)
OUT3	12.45	0.00	8.85	(leaching formula, root depth = 0.5)
OUT4	1.86	0.00	0.00	(regression model)
OUT5	0.00	0.00	0.00	(no erosion, rice only in lowlands)
Total	7.5	4.0	-9.8	

Yam

Harvested area: 1 175 ha 12 992 tonnes production

	N	P	K	
		(kg/ha)		
IN1	4.11	1.22	1.83	(macrolevel)
IN2	0.80	0.28	0.27	((available manure * loss * factor) / harvested area)
IN3	7.36	0.98	5.91	(macrolevel)
IN4	4.26	0.00	0.00	(only non-symbiotic)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	50.86	3.32	32.29	(production * nut content)
OUT2	5.25	1.33	8.51	(production * residue removal * nut content)
OUT3	0.00	0.00	8.69	(leaching formula, root depth = 0.5)
OUT4	1.96	0.00	0.00	(regression model)
OUT5	13.44	1.53	1.40	(7 tonnes/ha erosion)
Total	-55.0	-3.7	-42.9	

GHANA, WASSA AMENFI DISTRICT

Cassava

Harvested area: 7 700 ha 77 000 tonnes production

	N	P	K	
		(kg/ha)		
IN1	0.64	0.06	0.19	(macrolevel)
IN2	0.14	0.04	0.09	((available manure * loss * factor) / harvested area)
IN3	7.53	1.00	5.71	(macrolevel)
IN4	4.33	0.00	0.00	(only non-symbiotic)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	42.00	4.80	42.50	(production * nut content)
OUT2	13.80	2.73	4.26	(production * residue removal * nut content)
OUT3	0.00	0.00	8.87	(leaching formula, root depth = 0.6)
OUT4	1.49	0.00	0.00	(regression model)
OUT5	8.66	1.15	0.70	(5 tonnes/ha erosion)
Total	-53.3	-7.6	-50.4	

Cocoa

Harvested area: 240 961 ha 53 045 tonnes production

	N	P	K	
		(kg/ha)		
IN1	0.00	0.01	0.01	(40 ha fertilized with kg P and kg K)
IN2	0.00	0.00	0.00	(no organic inputs)
IN3	7.53	1.00	5.71	(macrolevel)
IN4	4.33	0.00	0.00	(only non-symbiotic)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	4.56	0.79	1.47	(production * nut content)
OUT2	1.53	0.17	4.45	(50% of husk lost, put on one heap or used for soap)
OUT3	4.15	0.00	8.83	(leaching formula, root depth = 0.7)
OUT4	1.39	0.00	0.00	(regression model)
OUT5	1.73	0.23	0.14	(1 tonnes/ha erosion)
Total	-1.5	-0.2	-9.2	

Cocoyam

Harvested area: 3 000 ha 21 000 tonnes production

	N	P	K	
		(kg/ha)		
IN1	4.11	1.22	1.83	(macrolevel)
IN2	0.24	0.06	0.16	((available manure * loss * factor) / harvested area)
IN3	7.53	1.00	5.71	(macrolevel)
IN4	4.33	0.00	0.00	(only non-symbiotic)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	32.20	2.10	20.44	(production * nut content)
OUT2	2.00	0.50	3.23	(production * residue removal * nut content)
OUT3	1.96	0.00	9.17	(leaching formula, root depth = 0.5)
OUT4	1.94	0.00	0.00	(regression model)
OUT5	12.13	1.61	0.99	(7 tonnes/ha erosion)
Total	-34.0	-1.9	-26.1	

Fallow

Harvested area: 7 300 ha 0 tonnes production

	N	P	K	
	(kg/ha)			
IN1	0.00	0.00	0.00	(no mineral fertilizer)
IN2	0.00	0.00	0.00	(input of manure is equal to removal of crop residues)
IN3	7.53	1.00	5.71	(macrolevel)
IN4	4.33	0.00	0.00	(only non-symbiotic)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	0.00	0.00	0.00	(no crop products)
OUT2	0.00	0.00	0.00	(removal of crop residues is equal to input of manure)
OUT3	7.84	0.00	8.83	(leaching formula, root depth = 0.5)
OUT4	1.39	0.00	0.00	(regression model)
OUT5	0.87	0.11	0.07	(0.5 tonnes/ha erosion)
Total	1.8	0.9	-3.2	

Maize

Harvested area: 5 650 ha 8 475 tonnes production

	N	P	K	
	(kg/ha)			
IN1	5.86	1.20	2.42	(macrolevel)
IN2	0.52	0.13	0.33	((available manure * loss * factor) / harvested area)
IN3	7.53	1.00	5.71	(macrolevel)
IN4	4.33	0.00	0.00	(only non-symbiotic)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	25.20	6.14	7.13	(production * nut content)
OUT2	2.18	0.43	4.82	(production * residue removal * nut content)
OUT3	3.83	0.00	9.30	(leaching formula, root depth = 0.9)
OUT4	2.20	0.00	0.00	(regression model)
OUT5	8.66	1.15	0.70	(5 tonnes/ha erosion)
Total	-23.8	-5.4	-13.5	

Oil-palm

Harvested area: 900 ha 10 800 tonnes production

	N	P	K	
	(kg/ha)			
IN1	1.50	1.13	2.57	(macrolevel)
IN2	0.00	0.00	0.00	(no organic inputs)
IN3	7.53	1.00	5.71	(macrolevel)
IN4	4.33	0.00	0.00	(only non-symbiotic)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	34.80	8.40	48.96	(production * nut content)
OUT2	4.44	0.68	4.00	(production * residue removal * nut content)
OUT3	0.00	0.00	9.27	(leaching formula, root depth = 1.0)
OUT4	1.58	0.00	0.00	(regression model)
OUT5	1.73	0.23	0.14	(1 tonnes/ha erosion)
Total	-29.2	-7.2	-54.1	

Plantain

Harvested area:	5 000	ha	40 000	tonnes production

	N	P	K	
		(kg/ha)		
IN1	0.33	0.08	0.65	(macrolevel)
IN2	0.15	0.04	0.09	((available manure * loss * factor) / harvested area)
IN3	7.53	1.00	5.71	(macrolevel)
IN4	4.33	0.00	0.00	(only non-symbiotic)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	5.60	0.70	27.36	(production * nut content)
OUT2	0.96	0.24	5.14	(production * residue removal * nut content)
OUT3	5.32	0.00	8.95	(leaching formula, root depth = 0.5)
OUT4	1.45	0.00	0.00	(regression model)
OUT5	5.20	0.69	0.42	(3 tonnes/ha erosion)
Total	-6.2	-0.5	-35.4	

Rice

Harvested area:	2 112	ha	2 746	tonnes production

	N	P	K	
		(kg/ha)		
IN1	4.07	1.02	3.00	(macrolevel)
IN2	0.00	0.00	0.00	(no organic inputs)
IN3	7.53	1.00	5.71	(macrolevel)
IN4	4.33	0.00	0.00	(only non-symbiotic)
IN5	22.88	7.65	2.48	(sedimentation of 1 mm/year, including enrichment factor)
OUT1	15.08	4.41	4.45	(production * nut content)
OUT2	1.47	0.30	4.65	(production * residue removal * nut content)
OUT3	10.26	0.00	9.34	(leaching formula, root depth = 0.5)
OUT4	1.90	0.00	0.00	(regression model)
OUT5	0.00	0.00	0.00	(no erosion, rice only in lowlands)
Total	10.1	5.0	-7.3	

Vegetables

Harvested area:	250	ha	1 500	tonnes production

	N	P	K	
		(kg/ha)		
IN1	4.25	0.76	2.08	(macrolevel)
IN2	5.88	1.52	3.74	((available manure * loss * factor) / harvested area)
IN3	7.53	1.00	5.71	(macrolevel)
IN4	4.33	0.00	0.00	(only non-symbiotic)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	54.00	5.46	15.48	(production * nut content)
OUT2	5.76	2.50	14.09	(production * residue removal * nut content)
OUT3	0.00	0.00	9.83	(leaching formula, root depth = 0.4)
OUT4	2.68	0.00	0.00	(regression model)
OUT5	17.33	2.30	1.41	(10 tonnes/ha erosion)
Total	-57.8	-7.0	-29.3	

Yam

Harvested area: 1 500 ha 27 000 tonnes production

	N	P	K	
		(kg/ha)		
IN1	4.11	1.22	1.83	(macrolevel)
IN2	0.24	0.06	0.16	((available manure * loss * factor) / harvested area)
IN3	7.53	1.00	5.71	(macrolevel)
IN4	4.33	0.00	0.00	(only non-symbiotic)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	82.80	5.40	52.56	(production * nut content)
OUT2	5.13	1.30	8.32	(production * residue removal * nut content)
OUT3	0.00	0.00	9.17	(leaching formula, root depth = 0.5)
OUT4	1.94	0.00	0.00	(regression model)
OUT5	12.13	1.61	0.99	(7 tonnes/ha erosion)
Total	-85.8	-6.0	-63.3	

KENYA, EMBU DISTRICT

Arrow roots

Harvested area: 260 ha 894 tonnes production

	N	P	K	
		(kg/ha)		
IN1	0.00	0.00	0.00	(No mineral fertilizer)
IN2	0.00	0.00	0.00	(no manure)
IN3	6.83	0.88	3.68	(derived from rainfall)
IN4	4.24	0.00	0.00	(only non-symbiotic)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	23.80	7.00	42.00	(production * nut content)
OUT2	2.66	0.70	4.34	(production * nut content * residue removal [20%])
OUT3	35.15	0.00	4.36	(leaching formula, root depth = 0.5)
OUT4	1.51	0.00	0.00	(regression model)
OUT5	0.00	0.00	0.00	(0 tonnes/ha erosion, grown in valley)
Total	-52.1	-6.8	-47.0	

Beans

Harvested area: 2 748 ha 1 240 tonnes production

	N	P	K	
		(kg/ha)		
IN1	5.70	5.60	0.00	(Staverman, 2003)
IN2	0.94	0.19	0.82	(2% of available manure)
IN3	6.83	0.88	3.68	(derived from rainfall)
IN4	16.01	0.00	0.00	(only non-symbiotic)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	16.70	1.31	10.56	(production * nut content)
OUT2	4.55	0.44	5.73	(production * nut content * residue removal [97%])
OUT3	44.83	0.00	4.50	(leaching formula, root depth = 0.6)
OUT4	2.36	0.00	0.00	(regression model)
OUT5	103.04	30.80	7.49	(7 tonnes/ha erosion)
Total	-142.0	-25.9	-23.8	

Cassava

Harvested area: 515 ha 5 280 tonnes production

	N	P	K	
		(kg/ha)		
IN1	0.00	0.00	0.00	(No mineral fertilizer)
IN2	0.00	0.00	0.00	(no manure)
IN3	6.83	0.88	3.68	(derived from rainfall)
IN4	4.24	0.00	0.00	(only non-symbiotic)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	127.13	7.18	82.02	(production * nut content)
OUT2	9.43	1.85	2.87	(production * nut content * residue removal [20%])
OUT3	10.88	0.00	4.36	(leaching formula, root depth = 0.6)
OUT4	1.51	0.00	0.00	(regression model)
OUT5	147.20	44.00	10.70	(10 tonnes/ha erosion)
Total	-285.1	-52.1	-96.3	

Coffee

Harvested area: 8 813 ha 12 800 tonnes production

	N	P	K	
		(kg/ha)		
IN1	59.10	13.20	0.00	(Staverman, 2003)
IN2	5.28	1.06	4.59	(36% of available manure)
IN3	6.83	0.88	3.68	(derived from rainfall)
IN4	4.24	0.00	0.00	(only non-symbiotic)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	4.80	0.32	4.00	(production * nut content)
OUT2	0.52	0.46	1.12	(production * nut content * residue removal [15%])
OUT3	25.95	0.00	5.15	(leaching formula, root depth = 0.9)
OUT4	9.70	0.00	0.00	(regression model)
OUT5	73.60	22.00	5.35	(5 tonnes/ha erosion)
Total	-39.1	-7.6	-7.3	

Cowpea

Harvested area: 280 ha 410 tonnes production

	N	P	K	
		(kg/ha)		
IN1	0.00	40.00	0.00	(recommended amount)
IN2	0.00	0.00	0.00	(no manure)
IN3	5.86	0.76	3.16	(derived from rainfall)
IN4	24.38	0.00	0.00	(only non-symbiotic)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	25.38	1.80	14.40	(production * nut content)
OUT2	11.06	0.64	6.40	(production * nut content * residue removal [97%])
OUT3	29.32	0.00	2.02	(leaching formula, root depth = 0.6)
OUT4	1.32	0.00	0.00	(regression model)
OUT5	70.84	30.80	6.90	(7 tonnes/ha erosion)
Total	-107.7	7.5	-26.6	

Fallow

Harvested area: 1 800 ha 18 000 tonnes production

	N	P	K	
		(kg/ha)		
IN1	0.00	0.00	0.00	(Staverman, 2003)
IN2	3.23	0.65	2.81	(4.5% of available manure)
IN3	6.83	0.88	3.68	(derived from rainfall)
IN4	4.24	0.00	0.00	(only non-symbiotic)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	0.00	0.00	0.00	(no crop products)
OUT2	2.04	0.26	2.21	(production * nut content * residue removal [5%])
OUT3	27.61	0.00	4.84	(leaching formula, root depth = 0.5)
OUT4	1.92	0.00	0.00	(regression model)
OUT5	7.36	2.20	0.53	(0.5 tonnes/ha erosion)
Total	-24.6	-0.9	-1.1	

Maize

Harvested area: 5 143 ha 10 452 tonnes production

	N	P	K	
		(kg/ha)		
IN1	18.10	8.10	1.80	(Staverman, 2003)
IN2	12.82	2.57	11.14	(51% of available manure)
IN3	6.83	0.88	3.68	(derived from rainfall)
IN4	4.24	0.00	0.00	(only non-symbiotic)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	40.65	3.86	33.13	(production * nut content)
OUT2	18.73	3.67	41.32	(production * nut content * residue removal [95%])
OUT3	33.57	0.00	6.59	(leaching formula, root depth = 0.9)
OUT4	5.45	0.00	0.00	(regression model)
OUT5	117.76	35.20	8.56	(8 tonnes/ha erosion)
Total	-174.2	-31.2	-73.0	

Napier

Harvested area: 602 ha 21 076 tonnes production

	N	P	K	
		(kg/ha)		
IN1	32.90	6.00	0.00	(Staverman, 2003)
IN2	10.74	2.15	9.33	(5% of available manure)
IN3	6.83	0.88	3.68	(derived from rainfall)
IN4	4.24	0.00	0.00	(only non-symbiotic)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	136.50	14.00	182.00	(production * nut content)
OUT2	0.00	0.00	0.00	(residue is crop products)
OUT3	21.75	0.00	5.97	(leaching formula, root depth = 0.9)
OUT4	7.07	0.00	0.00	(regression model)
OUT5	58.88	17.60	4.28	(4 tonnes/ha erosion)
Total	-169.5	-22.6	-179.2	

Potatoes

Harvested area: 678 ha 4 130 tonnes production

	N	P	K	
		(kg/ha)		
IN1	45.00	50.00	0.00	(Min. of Agriculture and GTZ, 1998)
IN2	0.00	0.00	0.00	(no manure)
IN3	8.54	1.10	4.60	(derived from rainfall)
IN4	4.68	0.00	0.00	(only non-symbiotic)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	41.42	3.05	37.16	(production * nut content)
OUT2	2.80	0.85	5.48	(production * nut content * residue removal [20%])
OUT3	99.51	0.00	5.98	(leaching formula, root depth = 0.4)
OUT4	7.63	0.00	0.00	(regression model)
OUT5	51.75	13.93	1.29	(3 tonnes/ha erosion)
Total	-144.9	33.3	-45.3	

Sorghum

Harvested area: 207 ha 189 tonnes production

	N	P	K	
		(kg/ha)		
IN1	10.00	4.35	0.00	(recommended amount)
IN2	6.25	1.25	5.43	(1% of available manure)
IN3	5.86	0.76	3.16	(derived from rainfall)
IN4	3.96	0.00	0.00	(only non-symbiotic)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	13.60	1.83	5.84	(production * nut content)
OUT2	8.38	3.57	22.66	(production * nut content * residue removal [85%])
OUT3	24.24	0.00	2.96	(leaching formula, root depth = 1.0)
OUT4	3.39	0.00	0.00	(regression model)
OUT5	80.96	35.20	7.88	(8 tonnes/ha erosion)
Total	-104.5	-34.2	-30.8	

Sweet potatoes

Harvested area: 140 ha 1 341 tonnes production

	N	P	K	
		(kg/ha)		
IN1	17.00	7.39	14.17	(recommended amount)
IN2	4.62	0.93	4.01	(0.5% of available manure)
IN3	6.83	0.88	3.68	(derived from rainfall)
IN4	4.24	0.00	0.00	(only non-symbiotic)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	90.04	8.62	70.88	(production * nut content)
OUT2	19.11	10.92	30.03	(production * nut content * residue removal [95%])
OUT3	23.52	0.00	7.50	(leaching formula, root depth = 1.0)
OUT4	4.26	0.00	0.00	(regression model)
OUT5	73.60	22.00	5.35	(5 tonnes/ha erosion)
Total	-177.8	-32.3	-91.9	

Tea

Harvested area: 1 092 ha 9 600 tonnes production

	N	P	K	
		(kg/ha)		
IN1	33.75	2.93	5.63	(recommended amount)
IN2	0.00	0.00	0.00	(no manure)
IN3	8.54	1.10	4.60	(derived from rainfall)
IN4	4.68	0.00	0.00	(only non-symbiotic)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	9.50	0.76	5.13	(production * nut content)
OUT2	0.03	0.00	0.00	(production * nut content * residue removal [15%])
OUT3	30.29	0.00	6.96	(leaching formula, root depth = 0.9)
OUT4	6.20	0.00	0.00	(regression model)
OUT5	17.25	4.64	0.43	(1 tonne/ha erosion)
Total	-16.3	-1.4	-2.3	

MALI, CMDT KOUTIALA REGION

Cotton

Harvested area: 144 713 ha 139 648 tonnes production

	N	P	K	(kg/ha)
		(kg/ha)		
IN1	37.96	11.37	11.85	(fertilizer input, from CMDT reports)
IN2	25.23	5.43	21.41	(organic fertilizer input, from CMDT reports)
IN3	5.40	0.72	4.27	(macrolevel)
IN4	3.73	0.00	0.00	(only non-symbiotic)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	23.16	2.80	6.27	(production * nut content)
OUT2	8.08	0.01	3.65	(prod * nut content * residue removal (1+61% burning))
OUT3	38.26	0.00	9.89	(leaching formula, root depth = 1.0)
OUT4	9.00	0.00	0.00	(regression model)
OUT5	7.59	2.31	0.28	(10/ha tonne erosion)
Total	-13.8	12.4	17.4	

Cowpea

Harvested area: 5 637 ha 2 559 tonnes production

	N	P	K	
		(kg/ha)		
IN1	0.00	0.00	0.00	(fertilizer input, from CMDT reports)
IN2	0.00	0.00	0.00	(organic fertilizer input, from CMDT reports)
IN3	5.40	0.72	4.27	(macrolevel)
IN4	14.86	0.00	0.00	(non-symbiotic + 55% of N fixed)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	11.62	1.36	0.32	(production * nut content)
OUT2	8.63	0.50	4.99	(production * nut content * residue removal (100%))
OUT3	5.22	0.00	4.14	(leaching formula, root depth = 0.6)
OUT4	0.96	0.00	0.00	(regression model)
OUT5	5.31	1.62	0.20	(7 tonnes/ha erosion)
Total	-11.5	-2.8	-5.4	

Fallow

Harvested area: 227 200 ha 0 tonnes production

	N	P	K	
		(kg/ha)		
IN1	0.00	0.00	0.00	(no mineral fertilizer)
IN2	0.00	0.00	0.00	(input of manure is equal to removal of crop residues)
IN3	5.40	0.72	4.27	(macrolevel)
IN4	3.73	0.00	0.00	(only non-symbiotic)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	0.00	0.00	0.00	(no crop products)
OUT2	0.00	0.00	0.00	(removal of crop residues is equal to input of manure)
OUT3	10.72	0.00	4.14	(leaching formula, root depth = 0.5)
OUT4	0.96	0.00	0.00	(regression model)
OUT5	0.38	0.12	0.01	(0.5 tonnes/ha erosion)
Total	-2.94	0.6	0.1	

Groundnut

Harvested area: 13 411 ha 7 564 tonnes production

	N	P	K	
		(kg/ha)		
IN1	0.00	0.00	0.00	(fertilizer input, from CMDT reports)
IN2	0.00	0.00	0.00	(organic fertilizer input, from CMDT reports)
IN3	5.40	0.72	4.27	(macrolevel)
IN4	19.86	0.00	0.00	(non-symbiotic = 65% of N fixed)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	18.84	0.96	3.95	(production * nut content)
OUT2	4.84	0.46	6.40	(production * nut content * residue removal (81%))
OUT3	0.00	0.00	4.14	(leaching formula, root depth = 0.5)
OUT4	0.96	0.00	0.00	(regression model)
OUT5	7.59	2.31	0.28	(10 tonnes/ha erosion)
Total	-7.0	-3.0	-10.5	

Maize

Harvested area: 57 020 ha 98 188 tonnes production

	N	P	K	
		(kg/ha)		
IN1	27.12	3.88	6.34	(fertilizer input, from CMDT reports)
IN2	7.18	1.54	6.09	(organic fertilizer input, from CMDT reports)
IN3	5.40	0.72	4.27	(macrolevel)
IN4	3.73	0.00	0.00	(only non-symbiotic)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	23.59	3.79	3.62	(production * nut content)
OUT2	16.39	2.07	25.76	(production * nut content * residue removal [80%])
OUT3	20.27	0.00	6.29	(leaching formula, root depth = 0.9)
OUT4	5.32	0.00	0.00	(regression model)
OUT5	3.80	1.16	0.14	(5 tonnes/ha erosion)
Total	-25.9	-0.9	-19.1	

Millet

Harvested area: 101 294 ha 87 012 tonnes production

	N	P	K	
		(kg/ha)		
IN1	5.38	0.72	1.37	(fertilizer input, from CMDT reports)
IN2	0.35	0.07	0.29	(organic fertilizer input, from CMDT reports)
IN3	5.40	0.72	4.27	(macrolevel)
IN4	3.73	0.00	0.00	(only non-symbiotic)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	16.49	5.12	4.66	(production * nut content)
OUT2	9.51	0.94	20.55	(production * nut content * residue removal (52%))
OUT3	3.80	0.00	4.43	(leaching formula, root depth = 1.0)
OUT4	1.68	0.00	0.00	(regression model)
OUT5	3.80	1.16	0.14	(5 tonnes/ha erosion)
Total	-20.4	-5.7	-23.8	

Rice

Harvested area: 5 569 ha 6 850 tonnes production

	N	P	K	
		(kg/ha)		
IN1	5.48	0.52	1.00	(fertilizer input, from CMDT reports)
IN2	0.04	0.01	0.03	(organic fertilizer input, from CMDT reports)
IN3	5.40	0.72	4.27	(macrolevel)
IN4	3.73	0.00	0.00	(only non-symbiotic)
IN5	11.76	4.77	0.58	(rice in valleys, 1 mm sedimentation per year)
OUT1	14.27	4.18	4.18	(production * nut content)
OUT2	4.86	0.99	15.41	(production * nut content * residue removal (35%))
OUT3	9.98	0.00	4.32	(leaching formula, root depth = 0.5)
OUT4	1.66	0.00	0.00	(regression model)
OUT5	0.00	0.00	0.00	(no erosion, rice is grown in valleys)
Total	-4.4	0.8	-18.0	

Sorghum

Harvested area: 130 254 ha 128 691 tonnes production

	N	P	K	
		(kg/ha)		
IN1	3.53	0.60	1.10	(fertilizer input, from CMDT reports)
IN2	0.05	0.01	0.04	(organic fertilizer input, from CMDT reports)
IN3	5.40	0.72	4.27	(macrolevel)
IN4	3.73	0.00	0.00	(only non-symbiotic)
IN5	0.00	0.00	0.00	(not relevant)
OUT1	16.80	1.98	2.96	(production * nut content)
OUT2	4.18	0.25	23.18	(production * nut content * residue removal (51%))
OUT3	2.13	0.00	4.33	(leaching formula, root depth = 1.0)
OUT4	1.41	0.00	0.00	(regression model)
OUT5	3.80	1.16	0.14	(5 tonnes/ha erosion)
Total	-15.6	-2.1	-25.2	

Annex 11

Abstracts of presentations from a 2003 workshop in Nairobi on scaling soil nutrient balances

THE AFRICAN NETWORK FOR SOIL BIOLOGY AND FERTILITY: NEW CHALLENGES AND OPPORTUNITIES

Soil fertility degradation has been described as the single most important constraint on food security in SSA. Soil fertility decline is not just a problem of nutrient deficiency but also of: (i) inappropriate germplasm and cropping system design; (ii) interactions with pests and diseases; (iii) the linkage between poverty and land degradation; (iv) often perverse national and global policies with respect to incentives; and (v) institutional failures. Therefore, tackling soil fertility issues requires a long-term perspective and a holistic approach. The African Network for Soil Biology and Fertility (AfNet) of the Tropical Soil Biology and Fertility Institute of the CIAT is devoted to overcoming this challenge. AfNet's ultimate goal is to strengthen and sustain stakeholder capacity to generate, share and apply soil fertility management knowledge and skills to contribute to the welfare of farming communities. This Africa-wide network has over 200 members from national agricultural research and extension services and universities from various disciplines, mainly soil sciences, social sciences and technology exchange. This paper highlights AfNet's main activities, which include: network field research activities, information and documentation, training and capacity building.

Bationo, A., Kimetu, J., Ikerra, S., Kimani, S., Mugendi, D., Odendo, M., Silver, M., Swift, M.J. & Sanginga, N.

ASSESSMENT AND MONITORING OF NUTRIENT FLOWS AND STOCKS TO DETERMINE APPROPRIATE NUTRIENT MANAGEMENT STRATEGIES FOR ARID AND SEMI-ARID LANDS

The problem is the migration of population from high to low potential areas, which results in increased pressure on land, with erratic rainfall, continued cultivation/land degradation, increasing soil fertility problems and depressed crop yields. The main objective of the project is to identify in close cooperation with the farmers the major constraints faced by small-scale farm households in the arid and semi-arid lands of Kenya, with special emphasis on nutrient balances. A second objective is to identify, through participatory design and testing, alternative production techniques that will alleviate constraints and contribute to the implementation of more sustainable agricultural production systems. The project is implemented in six villages with different farming systems. The NUTMON approach to inventory and monitoring is implemented twice per season (diagnostic phase). The results (usually nutrient balances, economic indicators, etc.) of this phase are taken back to the farmers for evaluation and designing (implemented using PLAR approach) options to solve the identified soil fertility constraints.

Gachimbi, L.N. & De Jager, A.

SOIL NUTRIENT BALANCES BY CLASS OF FARM IN SOUTHERN MALI

The mining of nutrients in SSA is one of the main causes of yield stagnation and decline. In order to improve the sustainability of agricultural production, several nutrient balances were performed in the southern Mali. These balances provide valuable information of a general order. Nevertheless, little information exists concerning the impact of the techniques used by different categories of farmers on the fertility of their soils. This study was carried out in two villages (Noyaradougou and M'Peresso) and for three classes (categories) of farms ranging from Class I (good management of soil fertility) to Class III (poor management). The study intends to analyse the management of nutrient flows by different categories in both villages and to capture the major evolutionary tendencies in a period of 3-4 years.

In both villages and for all classes, partial balances of NPK (more visible and easily measurable components of nutrient balances) are positive for cotton in contrast to millet and sorghum. The same balance for maize depends largely on production strategy and improves from Class I to Class III in both villages. Depending on the village, the partial farm balances for N oscillate between -2.5 and 12 kg/ha/year. The P balance is positive for all classes and both villages and varies between 2.9 and 6.6 kg/ha/year, while that for K is usually negative. The partial balances at farm level have improved over the years thanks to higher input levels in 1997 as compared to previous years, and to lower crop and residue yields in all classes, except for Class I in Noyaradougou. The complete nutrient balance takes 'easy to measure' (elements of partial balances) and 'difficult to measure' flows into account. The complete N and K balances are negative. The K deficit is less marked in Noyaradougou, where the cropping system is based largely on cotton-maize, than in M'Peresso, where millet and sorghum occupy 48 percent of the rotation systems with cotton. The complete P balance is positive in all cases.

Kanté, S., Smaling, E.M.A. & Van Keulen, H.

EXPERIENCES WORKING WITH RURAL COMMUNITIES TO ACHIEVE IMPROVED SOIL NUTRIENT BALANCES AND ORGANIC MATTER

Trials and demonstrations on farmers' fields have shown that proper fertilization and other technologies such as conservation tillage can increase crop yields by large margins in much of SSA. The challenge is now to improve the availability and accessibility of fertilizers and other technologies to farming communities. Benefits from improvements in input distribution would be greater if coupled with crop management systems that promote fertilizer-use efficiency. Declines in soil organic matter lead to soil degradation, resulting in weak fertilizer responses and so eroding profitability. Over the years, the African Centre for Fertilizer Development has developed programmes that place special emphasis on: facilitation of fertilizer supply to communities; and promotion of ISFM involving the use of chemical fertilizers, organic materials and other yield.

The results from work with rural communities indicate that the facilitation of input supply and proper farm management practices can improve nutrient balances and soil organic-matter levels considerably.

Muchena, S.C.

EFFECT OF COCOA PRODUCTION ON THE SOIL NUTRIENT BALANCE IN GHANA

In Ghana, cocoa is produced by small-scale farmers with a low level of management. These farmers do not use fertilizers. Thus, production has tended to decline over the years. The main gains in farm nutrients are through the process of cocoa-leaf-litter decomposition, which adds 119 kg/ha N, 8 kg/ha P and 22 kg/ha K to the soil each year. The main losses of nutrients from the farm are through harvesting. Based on the average annual dry cocoa yield of 300 kg/ha, the annual amounts of major nutrients removed from the soil through harvesting of the pods are 7.5 kg/ha N, 1.2 kg/ha P, 4.4 kg/ha K for the beans and 4.2 kg/ha N, 0.5 kg/ha P and 12.1 kg/ha K for the husks. This loss, when estimated for an annual marketable harvest of 400 000 tonnes of dry cocoa beans, is equivalent to 10 000, 1 640 and 5 840 tonnes of N, P and K respectively, which represents about 6 percent of the quantity of nutrients (NPK) returned to the soil through the litter. The non-use of fertilizer to replenish the nutrients removed through harvesting over long periods could be one of the causes of the declining cocoa production in Ghana.

Ofori-Frimpong, K., Afrifa, A.A. & Appiah, M.R.

A HIERARCHICAL METHOD FOR SOIL EROSION ASSESSMENT AND SPATIAL RISK MODELLING

The Ph.D. thesis titled “A hierarchical method for soil erosion assessment and spatial risk modelling: a case study of Kiambu District by Peter F. Okoth” has devised a new method for assessing soil erosion for three levels of a landscape system. The method used in the thesis identified farmers as the beneficiaries of the lowest field-plot level assessment, a group of farmers as the beneficiaries of the second level, and government agencies as the beneficiaries of the highest level, the landscape unit. Spatial attributes considered important for the farmer to manage include: crop selection, ground cover, and the placement of the crop in particular positions in the landscape. Footpaths and field-plot boundaries need to be managed in watersheds in order to curb or control the problem of soil erosion. Roads, built-up areas, school compounds, river valleys and stream banks need to be managed at the highest landscape unit level. The method proposes an interdisciplinary systems approach in soil erosion risk management involving interventions, policies, resources, landscape properties, processes, time, energy and space for each level to achieve sustainability.

Okoth, P.F.

WHY SOIL NUTRIENT BALANCES? SOME ALTERNATIVES

This paper challenges the objectives of nutrient balances, reviews their limitations, and suggests two alternative approaches for evaluating and measuring impacts of farming practices on soil productivity. The first approach distinguishes nutrient supply from: (i) current inputs (organic resources and soluble inorganic fertilizers), which depend on current management; and (ii) stored nutrients (slow turnover pool of soil organic matter and sorbed inorganic pools), which depend on past management. Current nutrient supply is a sensitive indicator of the effects of current management on soil productivity in the short term (1-2 seasons). Stored nutrient supply is an indicator of soil buffering and sustainability in nutrient supply over the long term (20 years). The principal input data required to estimate these indices are: (i) dry matter and nutrient contents of organic-litter inputs to the soil; (ii) amounts of inorganic fertilizer inputs; and (iii) organic carbon content of the topsoil. The framework is suitable, and more informative than nutrient budgets, for gauging potential impacts of alternative farming practices on short- and long-term soil productivity. However, like nutrient budgets, the input data is difficult to collect in systematic surveys and over large areas, and the model has several assumptions that are difficult to validate.

The second approach recognizes that soil ability to supply nutrients is only one dimension of soil quality. It fills a need for integrated indicators of soil quality that capture other dimensions of productive capacity and ecosystem function, such as ability to infiltrate and store water and resist erosion. Such indicators need to be easily measurable to permit monitoring of actual impacts of alternative farming practices on soil quality. To this end, the paper proposes and demonstrates the use of visible near-infrared reflectance (NIR) spectroscopy for deriving integrated indicators of soil quality that relate directly to plant productivity and soil enrichment-depletion processes (e.g. organic inputs, erosion). These are slow, ecological indicators that are responsive to natural variation and long-term management effects but not noise from short-term effects of current management and environmental conditions. This non-destructive technique allows large numbers of soil samples to be characterized rapidly (2 000 samples/week). The paper demonstrates the use of the technique, in conjunction with stable isotope determinations, to assess effects of historic land use change and management effects on soil quality. It shows how the use of these spectral indicators in conjunction with statistical techniques allow: (i) confounding effects of spatial correlation and environmental noise to be separated from management effects; and (ii) uncertainties in soil quality indicators to be quantified at different levels of aggregation. Geo-referenced observations of the spectral quality index can also be spatially interpolated over large areas (> 10^3 km^2) using satellite imagery. The paper also shows the use of NIR spectroscopy for rapid assessment of organic resource quality.

Shepherd, K.D. & Walsh, M.G.

FUNCTIONING OF SOIL FERTILITY GRADIENTS AT THE FARM LEVEL AND IMPLICATIONS FOR INTEGRATED SOIL FERTILITY MANAGEMENT

Most agricultural research and development organizations accept the ISFM paradigm as the paradigm for developing and disseminating improved soil management options. Technically, the ISFM paradigm stands for the combined utilization of organic and mineral inputs combined with resilient germplasm. Although nutrient balances in SSA have been shown to be negative at national and regional scales, when zooming in at the farm scale, large differences in nutrient balance can usually be observed between fields, some of the latter showing positive balances. This is driven mainly by concentration of available resources, both organic and mineral, on fields near the homestead. Such management practices, when implemented over long periods, result in substantial differences in soil fertility status between fields within a farm. Most of the time, these differences take the form of gradients, decreasing with distance from the homestead. While the existence of soil fertility gradients has been observed in most areas in SSA, little is known on how these gradients affect processes underlying ISFM practices, such as fertilizer-use efficiency or organic-resource decomposition. Several hypotheses have been formulated in efforts to unravel relationships between the soil fertility status of individual fields and the functioning of ISFM practices but little information is available to test these hypotheses. This presentation presents a strategy to determine soil fertility gradients, explore the links with farmers' appreciation of soil fertility status, and present preliminary evidence in relation to above-mentioned hypotheses. Obtaining this information would enable judgements on whether recommendations for input use need to be refined by taking into account soil fertility gradients existing at the farm level.

Vanlauwe, B.

THE SOIL-MASS BASIS FOR ASSESSING CHANGES IN SOIL PROPERTIES

High-resolution data are necessary to assess accurately changes induced by integrated natural resource management (INRM) strategies, which are often 20 percent or less. These changes are detectable, given the correct statistical design. However, systematic errors (as opposed to random error) introduced in soil sampling methods and laboratory analysis generate data that are either always greater than or less than the actual sample mean. This has resulted in mis-assessment of trial results, including failure to detect actual changes and indications of non-existent changes. The erratic and often non-logical data caused by systematic error have led many soil scientists to believe that changes in soil properties cannot be detected reliably or quantified. As a result of both inaccurate methods and scientist disinterest, changes in soil properties resulting from INRM strategies are rarely assessed accurately. This slows the identification of successful interventions to farmers. This presentation examines the most widespread cause of systematic error in soil sampling: sampling a soil to a given depth increment and assessing changes in that increment. Even minor changes in bulk density, which commonly occur over the course of a trial owing to natural processes or to INRM interventions, change the mass of a soil being sampled in a given depth increment. Where the soil is compacted during the course of a trial, this always results in an overestimation of nutrient stocks in a given depth increment, whereas where the soil is de-compacted, an underestimation occurs. Errors of 10-15 percent are not uncommon. Similar systematic errors can be introduced in the laboratory analysis. When combined with soil sampling errors, such errors generate misleading data and erroneous conclusions. Soil-mass sampling eliminates sampling errors caused by depth sampling, but requires methods that are not commonly employed. Ellert and Bettany (1995) concluded that “recent publications indicate a serious and persistent lack of awareness about the influence of soil mass on estimates of nutrient storage” - a conclusion that applies equally to nutrient-availability indices or soil-quality measures. Adoption of soil-mass sampling procedures, along with minor modifications to routine laboratory procedures, can virtually eliminate systematic error, so accelerating the identification of promising INRM interventions.

Wendt, J.

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FAO FERTILIZER AND PLANT NUTRITION BULLETIN

Scaling soil nutrient balances

Enabling mesolevel applications for African realities

Using data on three countries in sub-Saharan Africa, this report compares macro- and microlevel approaches to determine soil nutrient balances with an innovative mesolevel approach. It highlights the added value that a mesolevel approach can provide in terms of its usefulness to mesolevel stakeholders in articulating and targeting scale-specific soil fertility enhancing measures, and its validity as an entry point for policy-makers and private-sector intervention.

ISBN 92-5-105237-9 ISSN 0259-2495

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TC/M/Y5749E/1/12.04/1200